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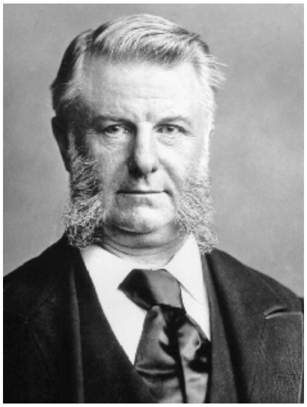
Biographies Index

ABEL, Sir Frederick Augustus (1827–1902); from 1893 first Baronet

▪ English chemist and military explosives specialist



Sir Frederick A. ABEL was born in Woolwich, south-east London. He was the eldest son of Johann Leopold ABEL, a music master in Kennington of German descent. After attending high school at the Johanneum in Hamburg, he studied chemistry at the London Polytechnic Institute and the Royal College of Chemistry. He first worked on aniline derivatives and then began offering instruction in practical chemistry to artillery officers at the Royal Military Academy in Woolwich, south-east London (1849). Succeeding Michael FARADAY as professor of chemistry at this prestigious institution (1851), he was appointed Ordnance Chemist (1854), then Great Britain's first Chemist to the War Department (1854–1888), and later also Chemical Referee to the British Government.

In conjunction with Sir Charles WHEATSTONE, ABEL investigated the applicability of electricity to military purposes (1856–1861) and worked as well on the detonation of explosives by electrical means. In 1866, he developed a process to prevent guncotton from exploding spontaneously by reducing it to a fine pulp that could be worked and stored with little danger. He measured the detonation velocity of nitroglycerin, then a subject of great controversy, and obtained a velocity of 1,525 m/s in tubes of 3 mm inner diameter (1867). Together with the British chemist Sir Andrew NOBLE he investigated the nature of chemical changes that result from firing explosives and measured the temperature of fired gunpowder (1875–1880). Together with (later Sir) James DEWAR, a Scottish professor of chemistry at Cambridge University, he invented and developed *cordite* (1889), a mixture made from purified ingredients of nitroglycerin, nitrocellulose, and petroleum jelly. This new safe and smokeless explosive, later adopted as the standard explosive of the British Army, was of vital importance in the First World War. One of ABEL's inventions was the so-called "Abel Heat Test" (1875) for checking the stability of a heated sample of cordite and other nitroglycerin and nitrocellulose explosives. It consists of heating a sample of the explosive in a test tube under rigid temperature control and estimating the degree of stability from the time taken to develop a brown color on a special paper suspended in the tube over the cordite. In the early 1880s, he studied the causes of firedamp explosions at the Seaham Colliery, Durham and their connections with the presence of finely divided coal dust in the air. This work also shed light on previously inexplicable but disastrous explosions in flour mills. ABEL also sat on the Royal Commission on Accidents in Mines (1883).

ABEL was knighted in 1883 and became a baronet in 1893. He received the Royal Medal (1887) for his research on explosives and the Bessemer Gold Medal (1897). He was President of the Chemical Society (1875–1877) and second holder of the Presidential Chair of the Institute of Chemistry (1880–1883) and the Committee on Explosives (1888–1891). During his career he also presided over other scientific organizations such as the Institution of Electrical Engineers (IEE), the Society of Chemical Industry (SCI), and the Iron and Steel Institute (ISI) and participated in the foundation of the Imperial Institute in London. In 1888, he was made Doctor of Science by Cambridge University.

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PICTURE. Courtesy Library and Information Centre, Royal Society of Chemistry, Cambridge, U.K.

ACKERET, Jakob (1898–1981)

▪ Swiss aerodynamicist; pioneer of aerodynamics

The son of Jakob ACKERET, a master locksmith, Jakob ACKERET was born in Zurich. After schooling at the Industrieschule Zürich, he studied mechanical engineering at the Eidgenössische Technische Hochschule (ETH) in Zurich (1916–1920) and became assistant to Prof. Aurel STODOLA, one of the most eminent representatives of mechanical engineering of his time. On STODOLA's recommendation he went to the University of Göttingen to study under Prof. Ludwig PRANDTL at the Aerodynamische Versuchsanstalt (AVA) to learn about the aerodynamics of aircraft. During the period 1921–1927 he worked out the essential theoretical fundamentals of supersonic flight and developed his famous linearized wing theory of thin sharp-edged supersonic airfoils – the so-called "Ackeret theory" (1925) – which the British physicist Geoffrey I. TAYLOR restated for the benefit of English-speaking readers (1932).

In the period 1925–1926, he directed the extension of PRANDTL's institute, which was financed by the German government and became the famous Kaiser-Wilhelm-Institut für Strömungsforschung. The new installations were used to study problems in gas dynamics and cavitation and to test new aerodynamic theories of flight at high speeds in practice. Subsequently, he became head of the hydraulic laboratory at the machine factory Escher-Wyss AG in Zurich and established testing procedures for hydraulic machines as well as for gas and steam turbines (1927–1931). In 1928, he qualified as a university lecturer at the ETHZ with a paper entitled *Über Luft-Kräfte bei sehr großen Geschwindigkeiten insbesondere bei ebenen Strömungen* ("On Air Forces at Very High Velocities, Particularly for Two-Dimensional Flows"), in which he coined the term *Mach number*. In 1931, he became *Privatdozent* (university lecturer) and 3 years later was appointed full professor of aerodynamics at the ETHZ and director of the newly founded Institut für Aerodynamik (IfA). He investigated the aerodynamic lift of rotating cylinders, known as the "Magnus effect," which led to the development of the Flettner-Rotor (1925) for possible driving and modernizing of sailing ships.

ACKERET's transfer of scientific know-how of modern aerodynamics to the construction and economic operation of steam and gas turbines was particularly successful and acknowledged worldwide. To increase the lift or to reduce the length of diffusers, he studied the removal of boundary layers by suction (1925–1927). He constructed the first closed-loop supersonic wind tunnel (1933–1934) which, built in cooperation with Brown Bovery & Co. (BBC) in Baden and Escher-Wyss AG in Zurich, was installed at ETH's new Maschinenlaboratorium. A similar wind tunnel was built under his direction at the Italian research center at Guidonia. He also treated the problem of cavitation (1938), which is essential for the trouble-free operation of steam turbines.

ACKERET was editor (1934–1961) of the bulletin Mitteilungen aus dem Institut für Aerodynamik ETHZ, where his most important results were also published.

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PICTURE. Courtesy of Prof. Leonhard KLEISER, Institut für Fluiddynamik, ETH Zurich, Switzerland.

NOTE. *Jakob ACKERET (1898–1981), Pionier der Aerodynamik.* Präsentiert zum 20. Todestag am 27. März 2001 von der Bibliothek der ETH Zürich; http://www.ethbib.ethz.ch/exhibit/ackeret/ackeret_frame.html. *See also* 13 pictures of Jakob ACKERET, "bildarchivonline" der ETH Bibliothek, Zürich; http://ba.e-pics.ethz.ch/ETH_Bibliothek/Standard/.

AIRY, Sir George Biddell (1801–1892)

▪ British mathematician and Astronomer Royal

George B. AIRY was born at Alnwick in Northumberland to William AIRY, a farmer and erstwhile collector of excise, and received his early education at private academies in Hereford and Colchester. With the support of his uncle he entered Trinity College in Cambridge (1819), took a scholarship (1822), and graduated as senior wrangler and first Smith's prizeman (1823). On his election to a fellowship at Trinity College, he became assistant mathematical tutor (1824) and Lucasian professor of mathematics at Cambridge (1826); illustrious philosophers such as Isaac BARROW and Sir Isaac NEWTON had preceded him as occupants of that traditional chair.

AIRY's scientific contributions in the fields of mathematics, physics, and astronomy, commencing in 1824, have been numerous and of high merit. His *Mathematical Tracts on Physical Astronomy* (1826) became a standard textbook used in the university. When the Plumian professorship of astronomy became vacant, he was appointed to the chair (1828), which was also connected to the directorship of the Cambridge Observatory. He gave popular lectures on statics, dynamics, hydrostatics, geometrical optics, and on the theory of undulations, a chief subject of interest throughout his professional career. When he became the seventh Astronomer Royal (1835–1881), he reorganized the Royal Greenwich Observatory and installed modern equipment; some pieces were of his own invention. Based upon the results of his astronomical and geodetic work, the Greenwich meridian was accepted as the international zero longitude and prime meridian of the world (1884).

AIRY detected a "long inequality" in the orbits of Venus and the Earth and improved the theory of their orbital motions. He determined the orbits of comets from observations (1839), introduced observation of sunspot phenomena (1873), and invented instruments for lunar observations. He measured gravity by swinging the same pendulum at the top and bottom of a deep mine and thus computed the density of the Earth (1854). His labors in connection with the Royal Observatory of

Greenwich, both in its development and in his personal scientific work, gave him a position of rare eminence.

In around 1841, AIRY turned his attention to the theory of tides. He wrote several papers on this subject, discussing separately the tides in the Thames, at Ipswich, Southampton, the coast of Ireland, and, later on, the tides at Malta. His chief work on this subject is his essay on *Tides and Waves* (1845) in which, for example, he discusses the broken water seen on the edge of a shoal, why the rise of tide takes less time than the fall, the solitary wave, the breaking of waves, the effect of the wind, and the effect of friction. Based on his theory of river tides, AIRY gave a general explanation that the retardation of the rotation of the Earth is caused by tidal friction. He also theoretically studied the motion and form of "waves of finite amplitude" in a broad, uniform canal of rectangular section and found, by methods of successive approximation, that in a progressive wave different parts will travel at different velocities. This pioneering analytical treatment of river tides might have motivated him to treat also sounds of finite amplitude in air, which, however, occupied him only a short period (1848–1849), while he maintained an interest in tidal waves through his later years. The same subject also stimulated James CHALLIS and George STOKES to turn to this problem on which they carried on a prolonged dispute.

AIRY made a number of worthwhile contributions to applied optics. For example, in the 1830s he carried out various experiments on the diffraction of Newton rings and on the intensity of light in the neighborhood of a caustic, and he attempted to theoretically explain the polarization of light. He used a water-filled telescope to test the effect of the Earth's motion on the aberration of light (1871). He studied astigmatism and was the first to correct astigmatism in the human eye (his own) by use of a cylindrical eyeglass lens (1825), a method that is still used. He was also actively involved in the improvement of lighthouses.

AIRY's continuous interest in the application of mathematics led to the solution of many physical and engineering problems. For example, his paper on strains in the interior of beams (1863) stimulated James C. MAXWELL to develop a general theory of stress diagrams for 3-D stress systems, while his studies on the causes of destructive steam-boiler explosions (1863) served immediate practical needs of greatest relevance. He was called in as a consultant on a project involving the removal of the magnetic-compass disturbance in iron-built ships and set up a magnetic department (1838), discovering that the deviation of the compass is accounted for almost entirely by the permanent magnetism of the hull (1840, 1856). He was also consulted on the launch of the SS *Great Eastern* (1858), the design of Big Ben (1850s), and the laying of the Atlantic telegraph cable (1866).

AIRY's scientific output was enormous; he wrote over 500 published papers and numerous books on mathematical physics and essays on history. From the Royal Society he received the Copley Medal (1831) for his successful optical theories and the Royal Gold Medal (1845) for his tidal investigations. He was awarded the Lelande Prize (1834) by the French Institute in honor of his discoveries in astronomy and the Telford Medal (1867) from the Institution of Civil Engineers. Twice the Gold Medal (1833, 1846) of the Royal Astronomical Society was awarded to him for his discovery of an inequality of long period in the movement of Venus and for his reduction of planetary observations. He was an honorary member of many scientific societies both at home and abroad. AIRY was knighted in 1872. He held honorary degrees from three great universities of Great Britain and was a foreign correspondent of various scientific societies.

The *Airy spiral* (an optical phenomenon visible in quartz) and the *Airy disc* (the central spot of light in the diffraction pattern of a point light source) are named after him. Astronomers named a crater on the near side of the Moon and a crater on Mars after him.

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PICTURE. Photo courtesy Deutsches Museum, Munich, Germany.

AL'TSHULER [Russ. *АЛЬТШУЛЕР*], Lev Vladimirovich (1913–2003)

▪ Russian physicist, dean of Russian shock wave physics

Lev V. AL'TSHULER was born in Moscow in a highly educated family; his father, a lawyer and active revolutionary, was later appointed to a post in the Soviet Ministry of Finance. After graduating from ordinary school in 1930, he worked for 2 years in the countryside. In 1932, he entered the Roentgen Laboratory of the Evening Institute of Mechanical Engineering in Moscow, which was headed at that time by Prof. E.F. BAKHMETEV, a recognized expert in X-ray analysis. BAKHMETEV cultivated in him a love for science, and studying under the famous scientist greatly influenced AL'TSHULER throughout his career. In 1933, AL'TSHULER entered the Faculty of Physics at Moscow State University. Being an external student in several subjects, he graduated from the University in 1936 ahead of schedule with a specialization in metal physics. He continued working at the Roentgen Laboratory till 1940; in 1939 the Laboratory was incorporated into the Institute of Engineering Science of the U.S.S.R. Academy of Sciences. In 1940, he was drafted and took part in World War II as a sergeant-mechanic and military technician of the Soviet Army, but in 1942 he was called back from the front to work in the U.S.S.R. Academy of Sciences. From 1942 to 1946, AL'TSHULER was Senior Research Associate at the Institute of Engineering Science. Together with Veniamin A. TSUKERMAN he developed pulsed radiography for studying shaped-charge effects on tank armor.

In the following years, the next important stage of his career began when he and TSUKERMAN were invited by Yulii KHARITON, then scientific director of the Soviet Nuclear Center Arzamas-16, to participate in the Soviet Atomic Project and to diagnose experimentally what happens to metals placed inside an explosive system. He worked at Arzamas-16 – now the All-Russia Research Institute of Experimental Physics (VNIIEF) located in the town of Sarov – from 1946 to 1969 and carried out experimental work in close cooperation with Yakov ZEL'DOVICH, Andrei SAKHAROV, and other prominent scientists. For example, he developed a method to measure the pressure of plane detonation waves; the basic results were obtained, together with Konstantin K. KRUPNIKOV, in 1948. In addition, equations of the state of compressed and heated explosion products were determined, dynamic methods for compressibility study developed, and the compressibility of fissile materials (uranium and plutonium) in the megabar range investigated. Together with Yakov B. ZEL'DOVICH and YU.M. STYAZHKIN he investigated at multiple megabars the compressibility of fissile materials and polymorphic transitions during shock compression. Nonmonotonous change of compressibility, corresponding to the reconstruction of energetic electronic spectra, was revealed for the first time by him in conjunction with A.A. BAKANOVA for rare-earth and alkaline metals. Together with M.N. PAVLOVSII, he studied phase transitions of the IV-group elements and ionic compositions, as wells as of minerals and rocks. Shock wave experiments, performed in conjunction with Aleksei M. PODURETS and Ryurik F. TRUNIN, showed that nearly all minerals and rocks form dense modifications under pressures above critical pressures. This significantly advanced the knowledge of the Earth's structure.

Returning to Moscow in 1969, AL'TSHULER headed a laboratory at the All-Union Institute of Optical-Physical Measurements. From 1989 he worked as Principal Research Associate at the Institute of High Temperatures of the Russian Academy of Sciences. Here he initiated efforts associated with the development of wide-range equations of state based on the joint interpretation of theoretical data and shock wave experiments. As founder of the Russian school of dynamic researches on the properties of shock-compressed materials, AL'TSHULER made a great contribution by teaching experts at this school. He is the author of over 60 scientific publications and coeditor of the book *Shock Waves and Extreme States of Matter* (New York, 2004).

He received the Stalin Prize in 1946 and the Order of Lenin in 1949. For a series of research efforts at VNIIEF, AL'TSHULER was awarded two more Stalin Prizes (1949, 1953), the Lenin Prize (1962), and three Orders of Lenin. He received the Shock Compression Science Award (1991) of the American Physical Society "in recognition of seminal and major contributions in the development of the field of shock wave compression of condensed matter." AL'TSHULER died on Dec. 23, 2003.

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PICTURE. Courtesy Prof. Anatoly MIKHAYLOV, director of the Institute of Experimental Gasdynamics and Physics of Explosion at VNIIEF, Sarov, Russia, who also contributed to the biography.

NOTE. His name has also been transliterated as AL'TŠULER.

ANTOLIK, Károly (1843–1905)

▪ Hungarian physicist and schoolmaster, inventor of the sooth method

Károly ANTOLIK was born in Kolbach (now Studenec) in East Slovakia, then a part of the Austro-Hungarian Empire, and studied physics and mathematics at the University of Budapest. There he became deeply influenced by Ányos JEDLIK, a prominent Hungarian physicist. After graduation, he taught at several Hungarian secondary schools. As a teacher at the Realschule Kaschau, he performed experiments with gliding sparks in order to analyze the mechanism of electric breakdown and tested various methods to record exactly the path of a spark discharge (1873–1874). Initially he experimented with various dust methods to mark spark traces such as LICHTENBERG's and CHLADNI's dust patterns. ANTOLIK was awarded a scholarship in Germany (1874–1875), where he spent the first semester in Berlin in the laboratory of Hermann VON HELMHOLTZ and the second semester under Robert W. BUNSEN

and Georg H. QUINCKE at the University of Heidelberg. Here he resumed his studies of dust patterns.

Today it is not known precisely where he invented his soot method. In his paper *Das Gleiten elektrischer Funken* ("The Gliding of Electric Sparks") published in 1875, he noted that he had discovered by chance the suitability of soot as a recording medium: bringing a small soot-coated glass balloon close to the spark of an influence machine, he noticed a well-marked trace of a spark in the soot. When he had sufficiently developed his new soot recording technique, he observed a significant phenomenon: soot-covered glass plates, brought close to crooked gliding sparks, showed complicated "V-shaped patterns" that, however, disappeared when the air between the plates was evacuated (1875). This suggested that the phenomenon must be of an acoustical nature, but ANTOLIK was too caught up in the interpretation of electrostatic phenomena and his hypothesis of the existence of a point of encounter between two types of electricity. Prof. Roland VON EÖTVÖS, the most prominent Hungarian physicist of the time, had in one of his private communications compared ANTOLIK's experiments to children's games. However, his experiments stimulated Ernst MACH, who after reading ANTOLIK's paper immediately turned to the study of his spark patterns. Yet in 1875 MACH scientifically proved that the V-shaped contours are of mechanical (acoustic) and not electrical origin and the result of a peculiar (irregular) interaction of strong acoustic waves (the term *shock wave* had not yet been established). Curiously enough, ANTOLIK, being familiar with MACH's work and also corresponding with him, remained unimpressed by MACH's skepticism on using soot patterns in the field of electrical research.

ANTOLIK eventually became director of the Staatliche Oberrealschule in Pressburg (now Bratislava, Czechia). Nicknamed the "Hungarian pioneer of spark patterns" by his contemporaries because of his numerous studies of spark discharges, he is considered today an early pioneer of 19th-century Hungarian physics.

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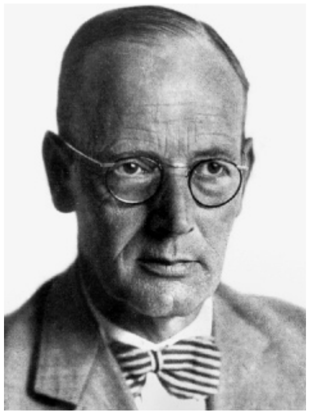
PICTURE. Courtesy Central Library of the Slovak Academy of Sciences (SAS), Bratislava, Slovak Republic.

BECKER, Richard Adolf (1887–1955)

▪ German theoretical physicist



Richard Adolf BECKER was born in Hamburg and attended high school at the famous Johanneum in Hamburg. He studied first zoology and at Freiburg wrote his Ph.D. thesis on the fly [*Diptera*] larva. Inspired by a lecture by Prof. Arthur SOMMERFELD, he decided to study physics. After graduation he worked as an assistant at the Institute of Physics of the TH Hannover and at the Kaiser-Wilhelm-Institut für Physikalische Chemie in Berlin. After carrying out research on explosives at the Sprengstoff AG Carbonit in Schlebusch, Cologne region (1913–1916), he worked for three years in Berlin as an assistant referee at the Waffen- und Munitionsbeschaffungsamt (Weapons and Munitions Supply Bureau). As a coworker of the chemist Friedrich BERGIUS at Heidelberg he got involved in coal liquefaction and the use of soft coal. He matriculated in Berlin at the Friedrich-Wilhelms-Universität with a thesis entitled *Stoßwelle und Detonation* ("Shock Wave and Detonation" 1922), a classical memoir in elementary shock wave physics famous for its lucidity in which he discussed in detail the effects of heat conduction and viscosity. After 4 years in industry he was appointed full professor of theoretical physics at the TH Berlin-Charlottenburg. In 1936, he took over the chair of theoretical physics at the University of Göttingen, where he remained until his death.

During World War II, BECKER managed the Erfahrungsgemeinschaft Hohlladungen (Shaped Charges Experience

Community) in Göttingen, which was founded in order to coordinate and exchange experimental work on the shaped charge effect at various German research institutes. His most renowned disciple and assistant was Werner Döring, cofounder of the *Zel'dovich-von Neumann-Döring detonation theory* (or *ZND theory*). Throughout his professional career Becker worked in various fields of basic research such as detonation, shock waves, plasticity, supra conductivity, nucleus formation, and ferromagnetism. His thorough contributions, also to difficult subjects, were characterized by great clarity of expression.

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PICTURE. Courtesy Staats- und Universitätsbibliothek (SUB) Göttingen, Germany; Sammlung Voit: R. Becker, Nr. 4.

NOTE. On Dec. 3, 1987, a Ballistic Seminar was given at the Ernst-Mach-Institut (EMI), Abteilung Weil am Rhein, Germany, on the occasion of R. Becker's 100th birthday.

Bernoulli, Daniel (1700–1782)

▪ Swiss mathematician, physicist, physician, and philosopher; cofounder of theoretical fluid dynamics

Daniel Bernoulli was born in Groningen, Holland, in a renowned family of scholars that had emigrated in 1622 from Antwerp, Holland to Basel, Switzerland. He was the

second son of Johann Bernoulli (1667–1748), who occupied the chair of mathematics at the University of Basel, and a nephew of Jakob Bernoulli (1665–1705), who also became a famous mathematician. His brother Nikolaus Bernoulli (1695–1726) became a mathematician and physicist.

At first Daniel Bernoulli was slated for a career in business, but he eventually turned to medicine instead. After completing his M.D. at the University of Basel on the action of the lungs (1721), he briefly worked with the physician Pierre Michelotti in Venice but soon reverted to the family tradition of mathematics and intensified his studies in mathematics, receiving instruction from his father and his beloved brother Nikolaus.

His first paper on mathematics, *Exercitationes mathematicae* (Venice 1724), won him much praise and an appointment as professor of mathematics at the Academy of St. Petersburg (1725–1733), joining there the young Swiss mathematician Leonard Euler, 7 years his junior, who had studied mathematics under Johann Bernoulli and, largely as the result of Daniel's influence, was also invited to St. Petersburg by Catherine I, Empress of Russia. During his stay in St. Petersburg he collaborated with Euler and in 1729 began writing his famous treatise *Hydrodynamica* (1738), which deals with the behavior of fluids; it was in this work that Bernoulli introduced the term *hydrodynamics*. This most important work on pure and applied fluid motion encompasses (1) a history of hydraulics, followed by a brief presentation of hydrostatics; (2) formulas for the outflow of a fluid from the opening of a container; (3) oscillations and energy loss of water in a tube immersed in a water tank; (4) a theory of the performance of hydraulic machinery and windmills; (5) discussions on the properties and motion of "elastic fluids" (*i.e.*, gases), such as the flow velocity of air streaming from a small opening; (6) the first formulation of the kinetic theory of gases; and (7) applications of the principle of conservation of energy to problems of fluid flow. He discovered that the total mechanical energy of a flowing fluid, which comprises the energy associated with fluid pressure, the gravitational potential energy of elevation, and the kinetic energy of fluid motion, remains constant – the so-called "Bernoulli equation" (or "Bernoulli theorem"). A manuscript draft of this famous *Hydrodynamica*, which already contains

most of the later published book and was left behind by him in St. Petersburg, is still preserved in the archives at the St. Petersburg Academy.

BERNOULLI left Russia and returned to Basel as professor, first of anatomy and botany (1733) and later of natural philosophy; *i.e.*, philosophy and physics (1750). He also treated special cases of percussion of bodies of non-symmetric geometry, demonstrated the propulsion of a small vessel by means of an ejected jet of water from the stern, invented a clepsydra (water clock) designed for the more accurate measurement of time on sea, investigated problems of friction and vibrating strings, and studied the nature and cause of ocean currents and tides of the sea.

BERNOULLI defined the "simple modes" and the frequencies of oscillation of a system with more than one degree of freedom, the points of which pass their positions of equilibrium at the same time, and demonstrated his concept on an arrangement consisting of a hanging rope loaded with several bodies. He determined their amplitude rates and frequencies and found that the number of simple oscillations equals the number of bodies; *i.e.*, the degrees of freedom. He was also the first to theoretically investigate the influence of elastic vibrations and translation on the percussion process. For a homogeneous straight elastic rod struck in its center of gravity by a percussive force, he calculated the loss of *vis viva* due to elastic vibrations (1770).

In addition to his continuous interest in applied mechanics and mathematics, BERNOULLI has been called the founder of mathematical physics. Later he studied differential equations, as well as probability and its applications to statistics. He also combined mathematics with medicine and, studying the rate of mortality resulting from smallpox in various age groups, introduced medical statistics.

For his numerous ingenious contributions to the natural sciences BERNOULLI won or shared the annual prize of the Paris Académie des Sciences ten times (as did his friend EULER) for the solution of designated problems.

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PICTURE. Photo courtesy Deutsches Museum, Munich, Germany.

BERTHELOT, Pierre Eugène Marcelin [Marcellin] (1827–1907)

▪ French organic and physical chemist; founder of thermochemistry

P.E. Marcelin BERTHELOT was born in Paris to Dr. Jacques Martin BERTHELOT, a physician. After attending courses in the Paris Faculty of Medicine and the Faculty of Science (1847–1849), he became a staff assistant to Antoine-Jérôme BALARD and demonstrator at the Collège de France (1851), where he took his Ph.D. in chemistry (1854). After carrying out further studies at the Ecole de Pharmacie, he graduated as a pharmacist (1858) and was appointed to the newly created chair of organic chemistry at the Ecole Supérieure de Pharmacie in Paris (1859). He became professor at the Collège de France (1864) and began

numerous researches on the acetylides of silver and copper (1862–1866), which inspired him to study other explosives as well. Following this period, BERTHELOT investigated the explosive force of gunpowder using his new calorimeter (1870). In the defense of Paris during the Franco-Prussian War (1870–1871), he investigated the possibility of extracting saltpeter for producing gunpowder within the city.

BERTHELOT studied the combustion of explosive mixtures of gases (1871), made measurements of the heat resulting from the formation of nitroglycerin (1874–1876), and extended his studies to determine their combustion temperature and velocity (1877). He also examined explosive mixtures of dust with air (1878) and fulminating mercury (1880). Investigations performed in collaboration with Paul VIEILLE on the velocity of the flame speed in explosive mixtures of gases led to the important discovery that the rate of explosion rapidly increases from the point of origin until it reaches a maximum, which remains constant, however long the column of gases might be, thus forming a new physicochemical constant important for theoretical and practical applications (1881). He called this rapidly propagating flame front *l'onde explosif* ("explosive wave"). For example, for oxyhydrogen BERTHELOT and VIEILLE measured a velocity of 2,841 m/s. BERTHELOT concluded that the explosion wave propagates upon impact of the products of combustion of one layer on the unburnt gases in the next layer and so on to the end of the tube at the rate of movement of the products of combustion themselves, thus identifying the maximum velocity of the flame with the mean translational velocity of the molecules themselves.

Besides his interest in the nature of explosion, BERTHELOT made major contributions to the synthesis of organic compounds and expanded our present knowledge of the history of alchemy. In 1868, he analyzed samples of the Orgueil Meteorite, a shower of stony meteorites of the rare carbonaceous chondrite type that fell on May 14, 1864 in southern France near the town of Peillerot. He reported finding in them hydrocarbons of the alkane family comparable to the oils of petroleum – thus confirming previous findings of Jöns J. BERZELIUS (1834) and Friedrich WÖHLER (1858) that some meteorites may contain complex organic matter, which gave rise to the question of possible extraterrestrial life.

BERTHELOT was Secretary of the Academy of Sciences and also a prominent politician, acting temporarily as Senator of France, Minister of Public Instruction, and Minister of Foreign Affairs. He is buried in the Panthéon in Paris.

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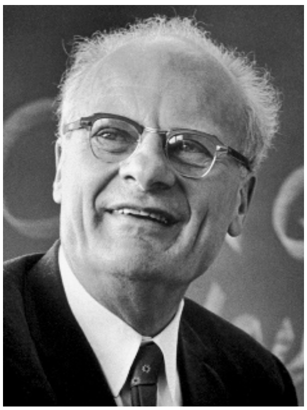
BETHE, Hans Albrecht (1906–2005)

▪ German-born U.S. theoretical physicist; father of nuclear astrophysics



The son of a university professor, Hans A. BETHE was born in Strassburg, Germany (now Strasbourg, Dépt. Alsace-Lorraine, France). He studied physics at the University of Frankfurt am Main. After taking his doctorate at the University of Munich under the supervision of Prof. Arthur SOMMERFELD (1928), BETHE began to teach theoretical physics at various German universities until 1933, when he fled Germany's growing Nazi regime. He went to England for the next 2 years, working in nuclear physics. He held a temporary position as lecturer at the University of Manchester for the period 1933–1934 and a fellowship at the University of Bristol in the fall of 1934. Together with the German-British physicist Rudolf E. PEIERLS he developed a theoretical model of the deuteron shortly after its discovery (1932). In February 1935 he was appointed assistant professor at Cornell University in Ithaca, NY (1935–1975). BETHE became renowned for his theory of how the Sun and stars use nuclear reactions to supply the energy they radiate. Partly in collaboration with U.S. physicist Charles L. CRITCHFIELD, he proposed the proton-proton chain (1938) and the carbon-nitrogen cycle (1939), the latter dominating in hotter stars. The end result of the reactions is the fusion of hydrogen nuclei to form helium nuclei. This process was independently suggested at the same time by Carl F. VON WEIZSÄCKER in Germany – so-called "Bethe-Weizsäcker cycle."

At the beginning of World War II, BETHE, on his own, formed a theory of the penetration of armor by projectiles (publ. 1945). Together with Edward TELLER he showed that behind strong shock waves a fluid (such as air) is in non-equilibrium because it takes a certain amount of time for the energy of the molecules corresponding to the vibrational degrees of freedom to arrive at equilibrium with the molecular energies corresponding to the translational and rotational degrees of freedom (1941). He began to work out a theory of shock wave propagation in dissociated gases, which became an important effect in the case of the detonation of nuclear weapons. During the war he worked for the Manhattan Project, leading the Theoretical Division of the Los Alamos Scientific Laboratory (1942–1945). In 1947, he edited the Los Alamos report *Blast Wave* (Rept. LA-2000), one of his most cited works among shock physicists, which describes how a nuclear weapon blast wave develops over time and distance. For an arbitrary equation of state he discussed theoretically the shock wave velocity in comparison to the sound velocity behind the shock front (1942). Together with John G. KIRKWOOD, he worked out an analytical approach to shock wave propagation in water for a number of explosives, the so-called "Kirkwood-Bethe propagation theory." Later he also made contributions to the design of the heat shield for ballistic missiles when they reenter the atmosphere.

After World War II, BETHE worked extensively on the collision of charged particles with atoms and pursued his earlier research on stellar nuclear energy for which he received the 1967 Nobel Prize for Physics "for his contribution to the theory of nuclear reactions, especially his discoveries concerning the energy production in stars." He also derived an equation of state of matter at supernuclear density ($\rho > 10^{16}$ g/cm^3) in order to determine the moment of inertia and mass of neutron stars (1974). In 1978, he began in a team to investigate the behavior of matter in a collapsing giant star that, due to gravitation, is supposed to give rise to a supernova explosion. Throughout his life BETHE remained vigorously opposed to U.S. H-bomb research, although after World War II he returned to Los Alamos as a consultant. He was a member of the President's Science Advisory Committee (1956–1959). At the age of 88, he called in an open letter on all scientists of all nations "to cease and desist from work creating, developing, improving, and manufacturing further nuclear weapons." In 1997, BETHE, at the age of 91, became

even more specific and wrote to U.S. President CLINTON that "the time has come to stop sponsorship also of *computational experiments*, or even create thought designed to produce new categories of nuclear weapons."

From 1944 he was a member of the U.S. Academy of Sciences and received its Draper Medal (1948). He was president of the American Physical Society (1954) and was awarded the U.S. Medal of Merit (1946), the Planck Medal (1955) of the German Physical Society, and the Eddington Medal (1963) of the Royal Astronomical Society. He also won the Enrico Fermi Prize (1961) of the U.S. Atomic Energy Commission. His main work was published in more than 250 papers in scientific journals. He also wrote many superb review articles or books on the theory of metals, quantum mechanics, atomic systems, nuclear physics, and field theory. BETHE died on March 6, 2005 at the age of 98 at his home in Ithaca, NY, near Cornell University.

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BLEAKNEY, Walker (1901–1992)

▪ U.S. physicist and gas dynamicist; pioneer of shock tube research

Walker BLEAKNEY was born in a country farmhouse near Echo, OR, and studied physics at Whitman College in Walla Walla (Washington State) and at Harvard. After completing his Ph.D. on the ionization of gases at the University of

Minnesota, he won a National Research Council Fellowship to continue research at Princeton University, where he remained for his entire career. He began to work in atomic and molecular ionization processes and built the most modern mass spectrometer of his time. During World War II, he became leader of a group to study and advise the U.S. Government on terminal ballistics. He began to improve the shock tube in order to generate well-defined shock profiles for a quantitative study of shock reflection, thereby coining the term "shock tube" (1946). He became director of the Princeton University Station, a division of the National Defense Research Committee (NDRC) of the Office of Scientific Research and Development (OSRD), and founded the Shock Wave Laboratory at Princeton University. One of his graduate students, Donald R. WHITE, discovered in 1951 "compound Mach reflection," later renamed "double Mach reflection." In the following year, his team began to apply the shock tube to study blast effects on model structures, then a field of growing interest because of the increasing menace of possible nuclear conflicts.

One of his team's major contributions was the study of real gas effects (*e.g.*, vibrational modes of diatomic molecules, dissociation, and ionization) that occur as the Mach number of the flow increases, and the extension and application of optical visualization techniques (*e.g.*, shadowgraphy, schlieren, and Mach-Zehnder interferometry) on shock reflection and shock wave superposition phenomena.

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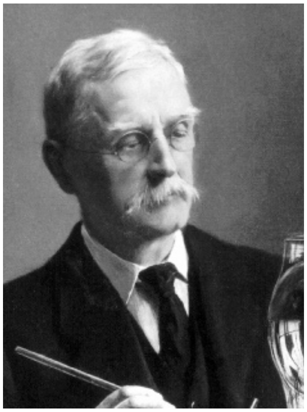
BOYS, Sir Charles Vernon (1855–1944)

▪ British experimental physicist and inventor

The son of Rev. Charles BOYS, Rector of Wing, Sir Charles Vernon BOYS was born at the Rectory of Wing, Uppingham, in Rutland. He graduated in mining and metallurgy at the Royal School of Mines, London. Later he became assistant professor at the Royal College of Science in South Kensington in London (1889–1897), now a constituent of the Imperial College, London. In 1886, BOYS took on the demonstratorship of the



Physical Society and also took over temporarily as acting professor. In 1897, he gave up his assistant professorship, also resigning his honorary positions as demonstrator and librarian for the Physical Society, and took up an applied science post at the Metropolitan Gas Referee in Westminster (1897–1939), which enabled him to continue his inventive activity without the onerous duties of teaching. During World War I, BOYS gave military advice on ballistics. In the period 1916–1917, he served as president of the Physical Society of London.

BOYS invented various scientific instruments such as (1) an *integraph* (1881), an integral machine for drawing the integral curve corresponding to any given curve (1881); (2) a *radio micrometer* (1883) for measuring minute streams of radiation such as the heat radiation from the Moon and other planets; (3) a *high-speed rotating mirror streak camera* (1892) to measure the pulse duration of submicrosecond spark light sources; (4) an improved *gas calorimeter* (1906) for testing the caloric value of gaseous fuels; and (5) a *high-speed rotating lens camera* – so-called "Boys camera" (1900).

His work on quartz fibers, utilizing their torsion for the measurement of minute forces, led to his conducting Cavendish-type experiments to improve the precision of the value obtained for the gravitational constant (1895), which was unsurpassed for decades.

Another important contribution to high-speed diagnostics and ballistics is his snapshot photography of supersonic bullets (1890–1893). Repeating Ernst MACH and Peter SALCHER's ballistic experiments (1886–1887), he simplified their experimental setup by using DVOŘÁK's method of shadowgraphy instead of TOEPLER's schlieren method and visualized the interaction and reflection of head waves. BOYS produced the first system to measure the spin rate of supersonic shot using specially prepared bullets and back light illumination along the trajectory. His streak camera, using a mirror of hardened steel rotating at 500 revolutions per second and a scan radius of 6 m, attained a writing speed of 37.5 mm/μs; time calibration occurred with a tuning fork. He measured the flash duration of various spark configurations, which resulted in a duration of between 0.1 and 1 μs.

As early as 1889 he suggested that the flickering of many lightning flashes indicated that they comprised several discharges down the same channel, which he eventually proved with his two-lens revolving camera. It had a fixed plate and two lenses mounted 180° apart on a rapidly rotating disk and allowed one to take two pictures with a minimum interframe time of 25 μs. From a comparison of the two pictures and a knowledge of the velocities of the lenses, he deduced the direction and speed of the developing discharge. Although he was in the habit of carrying this camera around for 26 years without obtaining a photograph, he eventually succeeded in photographing this progressive lightning during a visit of Mr. LOOMIS, a wealthy banker and amateur scientist who had a private laboratory at Tuxedo Park, NY (1928). His conclusion that the flash starts at the ground stimulated Basil F. SCHONLAND in South Africa to resume his technique (1934). BOYS also described a beautiful stereoscopic method of studying pictures in which they appear in two space dimensions and one time dimension.

BOYS was honored with the Royal Medal (1896), the Rumford Medal (1924) of the Royal Society, the Duddell Medal (1925) of the Physical Society, and the Cresson Medal (1939) of the Franklin Institute, Philadelphia. From 1888 he was a member of the Royal Society. He acted as president of the Physical Society of London (1916–1918) and was knighted in 1935. He bequeathed £1,000 to the Physical Society in 1944 "to be used to found a Boys Prize or a Boys Lecture or to be used in other manner at the discretion of the Council of the Society to further interest in experimental physics." In 1992, the Council of the Institute decided that the Charles Vernon Boys Prize should be changed to a medal and prize. This prestigious award recognizes outstanding contributions to experimental physics by a scientist under the age of 35.

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Sir Charles BOYS. Nature **133**, 677 (1934) — J.S.G.T. (anonymous): *Dr. BOYS on gas calorimetry*. Ibid. **133**, 710-711 (1934) — R.A.S. PAGET: *Sir Charles BOYS*. Proc. Phys. Soc. (Lond.) **56**, 397-403 (1944) — R.J. STRUTT: *C.V. BOYS*. Obit. Not. Fell. Roy. Soc. (Lond.) **4**, 771-788 (1944) — C.T.R. WILSON: *Sir Charles V. BOYS, F.R.S.* Nature **155**, 40-41 (1945) — R.V. JONES: *C.V. BOYS*. In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography*. Scribner, New York, vol. 15 (1978), pp. 59-61 — J.T. STOCK: *Sir C.V. BOYS, guardian of the flame*. Bull. Sci. Instrum. Soc. **23**, 2-6 (1989) — R. HILLIER: *High speed aerodynamics, be prepared for shocks*. Imperial College Inaugural Lecture (May 20, 1997) — G.J.N. GOODAY: *BOYS, Sir Charles Vernon*. In: (H.C.G. MATTHEW, ed.) *Oxford dictionary of national biography*. Oxford University Press, Oxford (2004), vol. 7, pp. 116-118.

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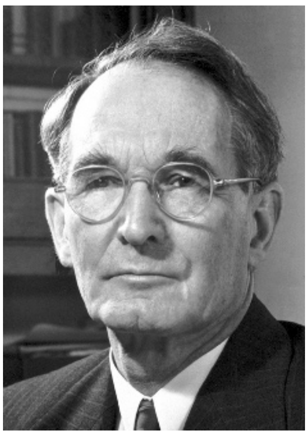
NOTE. Institute of Physics: *The Charles Vernon Boys Medal and Prize – previous winners*; http://about.iop.org/IOP/Awards/vernon.html.

BRIDGMAN, Sir Percy Williams (1882–1961)

▪ U.S. physicist and philosopher of science; dean of static high-pressure physics



Percy W. BRIDGMAN was born in Cambridge, MA, as son of Raymond Landon BRIDGMAN, a newspaperman and author. He received his early education in public schools in the nearby city of Newton until 1900, when he entered Harvard University. He studied physics at Harvard College and remained there his entire career: MA (1905), Ph.D. (1908), physics instructor (1910), assistant professor (1919), Hollis Professor of Mathematics and Natural Philosophy (1926), Higgins University Professor (1950), and professor emeritus (1954).

BRIDGMAN focused his researches on the effects of static high pressures on materials and their thermodynamic behavior. In 1905, he commenced his high-pressure studies which he continued throughout his whole career. His essential invention was the self-sealing feature of his first high-pressure packing, the so-called “Bridgman unsupported area seal” (1909), an eminent discovery for pioneering the field of high-pressure physics that, in his own words, “had a strong element of accident.” It was the starting point of many successive apparatus to produce high hydrostatic pressure without leak. Using initially a screw compressor (1908–1909), which allowed maximum pressures up to 6 kbar, he succeeded in pushing pressures up to 20 kbar by employing a hydraulic press (1910).

Further technical improvements, which allowed for gradual pressure increases up to 30 kbar, facilitated the first routine measurements of the mechanical, electrical, and thermal properties of matter. Still higher pressures up to about 400 kbar using his so-called “Bridgman opposed-anvil apparatus” were finally obtained in quasi-fluid systems (1930). He found that all liquids, with the exception of water, behaved qualitatively alike, the viscosity increasing with pressure at a rapidly increasing pressure. Subjecting water to high pressure, he found new crystalline forms; one, produced above 40,000 bars, was the so-called “hot ice” with a melting point of about 200 °C. In 1932, he took an active part in initiating a program at Harvard for high-pressure studies devoted to geophysical behavior. One of BRIDGMAN’s most famous undergraduate students was J. Robert OPPENHEIMER, a U.S. theoretical physicist who profited much from his contact with BRIDGMAN and later became scientific director of the Manhattan Project.

During World War II, BRIDGMAN participated in the Manhattan Project and measured the static compressibility of uranium and plutonium. He also studied the plastic flow of steel under high pressure as related to the strengthening of amour plate. It was at this time that he developed a method for increasing the yield point of artillery gun barrels by preliminary stretching with internal hydrostatic pressure. Although he never studied the behavior of matter under shock compression, his numerous papers on high-pressure research and his famous textbook *The Physics of High Pressures* (1931) have become standard sources of reference for shock physicists as well. His carefully measured data on static compression and on the state of matter (such as polymorphism and phase transitions) were often the only available source of information when physicists and military engineers began to investigate the behavior of solids and liquids under shock loading. He first suggested the use of the piezoresistive effect to measure static pressures and applied manganin wires (1950), a method which was resumed later in solid-state shock physics experiments. BRIDGMAN won the 1946 Nobel Prize for Physics “for the invention of an apparatus to produce extremely high pressures, and the discoveries he made therewith in the field of high-pressure physics.” In the early 1950s, he performed experiments on the compressibility of

glass up to static pressures of 200 kbar – approximately the upper limit accessible with his anvil compression technique.

His writings on high-pressure physics, spanning the years 1909–1963, combine experimental expertise with philosophic insight. He is renowned not only for his numerous contributions to static high-pressure research, but also for his brilliant mechanical constructions of high-pressure apparatus and accessories. In his book *Dimensional Analysis* (1931) he treated mathematically the Buckingham Pi Theorem (1914–1915), which has become the basis of most dimensional analyses in engineering dynamics. BRIDGMAN's interest in natural philosophy, pointing in the direction of the positivism of Ernst MACH and the Vienna Circle, was recorded in various books.

BRIDGMAN was a member of the National Academy of Sciences and various foreign academies. His high appreciation to the contribution of science is best reflected by the large number of awards bestowed upon him, such as the Rumford Medal (1917) by the American Academy, the Cresson Medal (1932) of the Franklin Institute, the Roozeboom Medal (1933) of The Netherlands Royal Academy, the Comstock Prize of the National Academy, the Research Corporation Award (1937), and the Bingham Medal (1951) of the Society of Rheology.

Since 1977 the *Bridgman Award* of the International Association for the Advancement of High Pressure Science and Technology (AIRAPT) is given biennially to researchers who make significant contributions to the progress of high-pressure physics.

A crater on the far side of the Moon is named for him.

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NOTE. AIRAPT, Harvard University, Cambridge, MA: *List of Bridgman Award recipients (1977–2005)*; http://www.unipress.waw.pl/airapt/.

BUNSEN, Robert Wilhelm Eberhard (1811–1899)

▪ German chemist and combustion researcher

Robert Wilhelm Eberhard BUNSEN was born in Göttingen to Christian BUNSEN, a professor of philology at the University of Göttingen. He studied chemistry, physics, mineralogy, and mathematics. In 1830, at the age of 19, BUNSEN earned a Ph.D. at the University of Göttingen under chemistry professor Friedrich STROMEYER and set off to study in Paris, Berlin, and Vienna. After touring Europe and visiting various factories, laboratories, and places of geological interest

(1830–1833), he became lecturer at the University of Göttingen (1833) and the Polytechnic School at Kassel (1836–1838). In Kassel he succeeded Friedrich WÖHLER, a pioneer in organic chemistry. Thereafter, BUNSEN accepted a position as an *Extraordinarius* (associate professor) of chemistry (1838–1842) at the University of Marburg, and in 1852 he succeeded Leopold GMELIN, a physiological chemist, at the University of Heidelberg as *Ordinarius* (full professor), where he stayed until his retirement in 1889. Most of his research he carried out at his new laboratory at Heidelberg University, which was constructed for him by the government of Baden (1855).

BUNSEN invented various instruments, such as the carbon-zinc battery or *Bunsenbatterie*, a filter pump for washing precipitates, and a thermopile. He devised a sensitive ice calorimeter and a vapor calorimeter, used magnesium to provide a brilliant light source, and improved a gas burner for use in spectroscopy – the famous *Bunsenbrenner* (Bunsen burner). Together with Gustav KIRCHHOFF he worked out the spectral analysis that later allowed BUNSEN to discover cesium and rubidium. While investigating compounds of cacodyl, an arsenic-containing organic compound, he lost the use of his right eye in an explosion of cacodyl cyanide. Most of his life he dedicated to the study of gases, particularly to the combustion process of gaseous mixtures and to the temperature of flames, which he determined by measuring the maximum pressure produced at the moment of explosion using a reaction vessel that, closed by a valve, was coupled to a weight-loaded lever arrangement – in construction similar to a safety valve. He investigated the ignition process of an oxyhydrogen atmosphere by using a rotating stroboscopic disk that had a known rate of rotation and that was comprised of radiating segments. Looking through his rotating disk at a white surface illuminated by the light from exploding gases, he could measure the duration of illumination. Together with the Russian chemist Léon SCHISCHKOFF he was the first to investigate exactly the chemical reactions of exploding gunpowder (1857). He compiled his research on the phenomena of gases into his only book, *Gasometrische Methoden* (1857). He observed that an explosion does not occur simultaneously in the whole test chamber but rather has a finite propagation velocity. Using a narrow tube he attempted to determine the rate at which an explosion is propagated and (erroneously) came to the conclusion that for a mixture of hydrogen and oxygen this was 34 m/s and for a mixture of hydrogen and carbon monoxide about 1 m/s (1867). However, subsequent studies carried out in France {BERTHELOT ⇨1881; BERTHELOT and VIEILLE ⇨1882; MALLARD and LE CHÂTELIER ⇨1883} and in England {HARCOURT ⇨1880; DIXON ⇨1877 & 1881} showed that this low rate of explosion only forms during the initial period of the combustion before the explosion wave attains its maximum velocity, which, in the case of a detonating mixture of hydrogen and oxygen, amounts to nearly 3,000 m/s.

BUNSEN was elected Foreign Fellow of the Royal Society (1858) and honored by several European societies. The Copley Medal (1860) was awarded to him, and, together with his German colleague KIRCHHOFF, he received the first Davy Medal (1877).

Astronomers named a crater on the near side of the Moon after him. The *Deutsche Bunsen-Gesellschaft für Physikalische Chemie e.V.* (German Bunsen Society for Physical Chemistry) at Frankfurt/Main, established in 1894, promotes the scientific and technical aspects of physical chemistry, with particular emphasis on the interaction between science and technology. The *Robert Wilhelm Bunsen Medal* has been established by the European Geosciences Union (EGU), Division of Geochemistry, Mineralogy, Petrology and Volcanology, in recognition of BUNSEN's scientific achievements. The first winners were the Canadian experimental chemist Terry M. SEWARD (2005) and the French physicist and geochemist Pascal RICHET (2006).

ORIGINAL WORKS. *Untersuchungen über die Kakodylreihe.* Ann. Chem. Pharm. **37**, 1-57 (1841); Ibid. **42**, 14-46 (1842); **46**, 1-48 (1843) — *On the radical of the Kakodyl series.* Phil. Mag. **20** [III], 382-393 (1842) — *Untersuchungen über die chemische Verwandtschaft.* Ann. Chem. Pharm. **85**, 137-155 (1853) — *Gasometrische Methoden.* Vieweg, Braunschweig (1857, 1877); Engl. translation by H.E. ROSCOE: *Gasometry. Comprising the leading physical and chemical properties of gases.* Walton & Maberly, London (1857) — With L. SCHICHKOFF: *Chemische Theorie des Schießpulvers.* Ann. Phys. **102** [II], 321-353 (1857); *On the chemical theory of gunpowder.* Phil. Mag. **15** [IV], 489-512 (1858) — *Über die Temperatur der Flammen des Kohlenoxyds und Wasserstoffs.* Ann. Phys. **131** [II], 161-179 (1867) — *On the temperature of a flame of carbonic oxide and hydrogen.* Phil. Mag. **34** [IV], 489-502 (1867) — W. OSTWALD and M. BODENSTEIN (eds.) *Gesammelte Abhandlungen von Robert BUNSEN.* 3 vols., Engelmann, Leipzig (1904).

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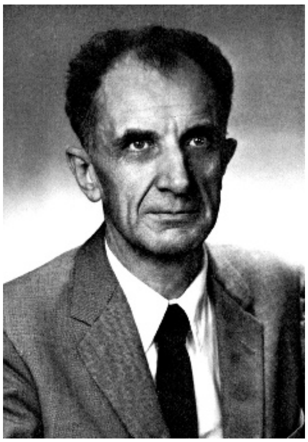
— W. OSTWALD: *Robert W. BUNSEN.* L. Joachim, Leipzig (1923) — K. FREUDENBERG: *150. Geburtstag R.W. BUNSEN.* Physik. Blätter **17**, 111-113 (1961) — S.G. SCHACHER: *R.W. BUNSEN.* In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography.* Scribner, New York, vol. 2 (1970), pp. 586-590 — K. HENTSCHEL: *Gustav Robert KIRCHHOFF (1824–1887) und Robert Wilhelm BUNSEN (1811–1899).* In: (K. VON MEŸENN, ed.) *Die großen Physiker.* C.H. Beck'sche Verlagsbuchhandl., München (1997), vol. 1, pp. 416-430.
PICTURE. Courtesy Universitätsarchiv Heidelberg, Germany.
NOTE. European Geosciences Union (EGU), Katlenburg-Lindau, Germany: *Robert Wilhelm Bunsen Medal and list of Robert Wilhelm Bunsen medallists*; http://www.copernicus.org/EGU/awards/robert_w_bunsen_overview.html.

BUSEMANN, Adolf (1901–1986)

▪ German aeronautical engineer; father of the swept-wing concept



Adolf BUSEMANN was born in Lübeck and studied mechanical engineering at the TU Braunschweig (1920–1924), where he also earned his Ph.D. under the supervision of Prof. Otto FÖPPL (1924). In Göttingen he began working in aeronautical research at the Kaiser-Wilhelm-Institut (KWI) [now Max-Planck-Institut (MPI)] für Strömungsforschung under the guidance of Prof. Ludwig PRANDTL (1925). This period of his life significantly determined his future scientific career. Together with PRANDTL he worked out a method of characteristics for 2-D supersonic flow, the so-called "Prandtl-Busemann method," and developed the shock polar diagram (1928). When Jakob ACKERET left Göttingen, he succeeded him as department head (1927–1931). He habilitated on a subject of applied mechanics and became *Privatdozent* (university lecturer) at the University of Göttingen (1930–1931) and at the University of Dresden (1931–1935), teaching fluid mechanics and thermodynamics.

At the 5th Volta Conference in Rome (1935), which was dedicated to the topic *Le alte velocità in aviazione* ("High Velocities in Aviation"), he suggested "sweepback wings" (or "swept wings") [Germ. *gepfeilte Tragflügel*] for high-speed aircraft and showed how their properties might solve many aerodynamic problems at speeds just below and above the speed of sound. Sweepback wings, resembling the tip of an arrow, hinder bow waves from striking the wings, thus reducing aerodynamic drag and preventing shock stall. One year later, the German Air Force made his concept of swept wings a state secret. In the 1930s, he also suggested a supersonic airframe design, later much discussed and known as the "Busemann biplane." It uses two identical wing surfaces facing each other, which results in zero wave drag – thus prohibiting the formation of a sonic boom – but, unfortunately, also in zero lift. His concept was investigated vigorously in Japan for the possible application to Boomless Supersonic Transport (Paper AIAA-2006-654).

In 1936, he became professor and director of the newly founded Institut für Gasdynamik of the Luftfahrtforschungsanstalt Hermann Göring at Braunschweig, a huge camouflaged aerodynamic research facility that remained unnoticed by the Allies throughout the war. He began to analyze the nature of supersonic lift, which laid the foundation for the aerodynamic design of German jet planes of World War II. BUSEMANN's idea could not be used until engines were developed to provide the high speed. In Germany, the Messerschmitt Me-262 (the first operational jet airplane) and the Me-163 (the fastest flying WWII aircraft and the only operational rocket-powered fighter) had sweepback wings. The German A4b, a long-distance version of the rocket V2 designed at the Heeresversuchsanstalt (HVA) Peenemünde under the leadership of Walter DORNBERGER and Werner VON BRAUN, had also sweepback wings.

After the war BUSEMANN worked in England at Farnborough, but after one year he decided to work for the NASA at Langley Research Center in Hampton, VA (1947–1964). In 1963, he became professor of fluid mechanics at the University of Colorado. After his retirement he lived in Boulder, CO.

Still during PRANDTL's lifetime, he became foreign scientific member of the Max-Planck-Institut für Strömungsforschung (1950). He received the Ludwig-Prandtl-Ring (1966), the highest award of the Wissenschaftliche Gesellschaft für Luft- und Raumfahrt, and shortly thereafter became *doctor honoris causa* of the University of Aachen. He was a Fellow of the American Astronautical Society (from 1968) and elected member of the National Academy of Engineering (1970).

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CARRÉ, Louis (1663–1711)

▪ French mathematician, physicist, and science writer

Louis CARRÉ was born at Clofontaine (Dépt. Seine-et-Marne) to a laborer and was set to become a priest. However, after finishing his studies in theology, he refused to take orders and became secretary of the famous philosopher and theologian Nicolas MALEBRANCHE (1638–1715), where he remained and continued his studies. In 1697, he was admitted to the Paris Academy of Sciences. His fields of interest included mathematics, geometry, fluid dynamics, and acoustics, particularly musical acoustics. In 1700, he published the first complete work on the integral calculus under the title *A Method of Measuring Surfaces and Solids, and Finding their Centers of Gravity, Percussion, and Oscillation*.

In 1702, CARRÉ reported on curious ballistic experiments in which he observed the destructive action of bullets being fired in a wooden tank filled with water, a phenomenon later termed *hydraulic ram* or *hydrodynamic ram*. It was certainly known to have happened in armed conflicts but had hitherto never been perceived or even analyzed scientifically. Hydrodynamic ram has become a present-day problem related to protecting aircraft fuel tanks against ballistic impact. CARRÉ also speculated on the trajectory and resistance that a bullet undergoes when striking a surface of water at an oblique angle, mentioning in connection with this the phenomenon of water ricocheting (1705). In 1707, he reported to the Academy on the first ballistic pendulum experiments made by Jacques CASSINI {⇨1707}. His memoirs were printed in the volumes of the Memoirs of the French Academy of Sciences, from 1701 to 1710.

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SECONDARY LITERATURE. B.L.B. FONTENELLE: *Eloge de M. CARRE.* Hist. Acad. Sci. Paris (1711), pp. 132-139 — Anonymous: *CARRÉ (Lewis).* In: (A. CHALMERS, ed.) *The general biographical dictionary: containing an historical and critical account of the lives and writings of the most eminent persons in every nation.* Nichols, London, vol. VIII (1813), pp. 283-285.

CAVENDISH, Henry (1731–1810)

▪ British experimental chemist and physicist

Henry CAVENDISH was born in Nice, southern France (Dépt. Alpes-Maritimes) to Lord Charles CAVENDISH, third son of William, second duke of Devonshire. He studied mathematics at St. Peter's College (now Peterhouse), Cambridge (1749–1753), but left the university without a degree. After touring Europe with his brother Frederick, he lived a frugal life at 13 Great Marlborough Street in Soho, London (1753–1784), and decided to experiment in physics and chemistry in his private laboratory. In 1771, at the age of 40, he became a millionaire through the inheritance of a fortune that made him, according to Jean-Baptiste BIOT, a contemporary French scientist, "the richest of all learned men, and very likely also the most learned of all the rich." In the late 1780s, he moved his laboratory to a large villa in Clapham Common, a fashionable suburb of London, where he set up a well-equipped laboratory and library, and became an eccentric scientist.

CAVENDISH – throughout his research inspired by Sir Isaac NEWTON's *Principia* (1687), his model of exact science – searched for the forces of particles. However, contrary to NEWTON, who assumed the existence of extended corpuscles, CAVENDISH preferred point-particles as proposed by some contemporary natural philosophers (*e.g.*, John MICHELL and Roger J. BOSCOVICH). CAVENDISH divided mechanical effects into visible motions and invisible vibrations, the latter being linked with active and latent heat. He planned to work out a theory of motion using the principle of conservation of mechanical momentum, the product of mass and velocity. He included the hidden momenta contributed by elasticity and gravitation and identified heat with the mechanical momentum of the vibrations of invisible particles. Mechanical momenta, he argued, must be conserved in heat exchanges and were applied to sound, water waves, and the heating effects of light. However, he could not yet explain basic phenomena such as the relation between mechanical heat and measurable temperature changes when bodies were in different physical states. In the 1760s, he started experiments on heat, and in the 1780s, responding to the caloric theory of the prominent French scientists Antoine-Laurent LAVOISIER and Pierre-Simon DE LAPLACE, drafted a long paper applying his early theory of mechanical momentum to thermal phenomena, attempting to extend his thermal mechanics to percussion, expansion, the electrical heating of wires, and the conversion of mechanical into thermal effects.

His ingenious research in chemistry and physics is characterized by a quantitative approach. He performed numerous scientific investigations but published only 20 articles and no books. He tackled many puzzling phenomena of his time, *e.g.*, the composition of air, the nature and properties of hydrogen, the specific heat of certain substances, the composition of water, and various properties of electricity. In order to establish that hydrogen gas was a substance entirely different from ordinary air, he calculated their densities as well as the densities of several other gases. He found that common air, as well as air brought by a balloon from the upper atmosphere, is made up of nitrogen in a 4:1 ratio by volume. He also showed that water is composed of oxygen and hydrogen.

Apparently, his only contribution relating to explosions was his investigation of the nature of hydrogen. He isolated carbon dioxide, then called "fixed air," and hydrogen (1766), which he called "inflammable air," and measured their specific weights. To uncover also the properties of hydrogen, he studied various mixtures of hydrogen and air. He subjectively measured the combustibility of air by the loudness of the explosion when detonated with inflammable air – a dynamic pressure gauge of sufficiently short response was not yet available to him. To find the volume ratio leading to the strongest explosions, he constructed a "measurer of explosions of inflammable air," which was the first instrument to quantitatively measure the efficiency of a gas explosion. Stimulated by experiments on an exploding mixture of air and hydrogen carried out in previous years by the Birmingham scientist John WARLTIRE, he made the important discovery that the combustion product of hydrogen and oxygen, deposited as dew on the walls of the reaction vessel, is pure water, thus showing that water is not a basic chemical element (then the common opinion) but rather a chemical compound formed from hydrogen and oxygen.

CAVENDISH also performed careful eudiometric measurements of the constitution of atmospheric air and discovered that after combustion of substances the residual air contains not only nitrogen but also another indifferent component (1783–1788). Later experiments by Sir William RAMSAY

and Lord RAYLEIGH showed that this inert component is a new element, which they called “argon” (1895). At the age of 67, CAVENDISH performed one of the most difficult measurements in the history of physics, which allowed him to calculate the mass of the Earth (1798): the determination of the gravitational constant between small bodies – since then known as the “Cavendish experiment.”

CAVENDISH was also interested in applied science. For example, in the early 1770s he served as member of a committee charged with the practical task of devising the best method of protecting the Purfleet powder magazine from lightning. In the 18th century, Purfleet, a town in Essex, was a major storage location for gunpowder in outer London that had burned down after a lightning strike. CAVENDISH took a leading role in the long-running debate about the appropriate shape of lightning rods. Eventually, the committee recommended the erection of pointed rather then blunted rods, with a minute description of their construction.

Astronomers named a crater on the near side of the Moon after him. The Cavendish Laboratory at Cambridge University was not named after him, but rather after the seventh duke of Devonshire, Spencer Compton CAVENDISH, who was chancellor of the University and who in 1879 donated the necessary funds to establish the laboratory.

ORIGINAL WORKS. *Three papers, containing experiments on factitious air* [1766]. Phil. Trans. Roy. Soc. Lond. **56**, 141-184 (1767) — With W. WATSON, B. FRANKLIN, and J. ROBERTSON: *Report on lightning conductors for the powder magazines at Purfleet. To the president and council of the Royal Society* (Aug. 21, 1772). In: (B. FRANKLIN and W.T. FRANKLIN, eds.) *Memoirs of the life and writings of Benjamin FRANKLIN.* H. Colburn, London (1818/1819), pp. 197-202 — *An account of a new eudiometer.* Phil. Trans. Roy. Soc. Lond. **73**, 106-135 (1783) — *Experiments on air.* Ibid. **74**, 119-153, 170-177 (1784); Ibid. **75**, 372-384 (1785) — *A measurer of explosions of inflammable air* [laboratory note]. In: (E. THORPE, ed.) *The scientific papers of the honourable Henry CAVENDISH, F.R.S.* Cambridge University Press, Cambridge, U.K., vol. II (1921): *Chemical & dynamical*, pp. 318-320.

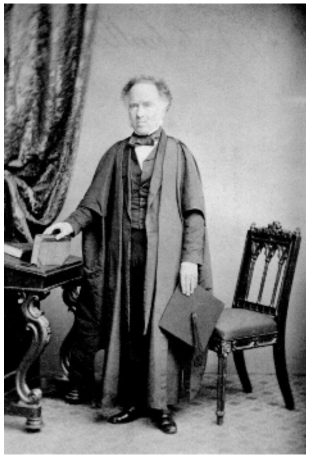
SECONDARY LITERATURE. H. BROUGHAM: *CAVENDISH.* In: (H. BROUGHAM, ed.) *Lives of men of letters and science: who flourished in the time of GEORGE III.* C. Knight, London (1845), vol. I, pp. 250-259 — A.J. BERRY: *Henry CAVENDISH: his life and scientific work.* Hutchinson, London (1960) — R. MCCORMMACH: *Henry CAVENDISH: a study of rational empiricism in 18th-century natural philosophy.* Isis **60**, 243-306 (1969); *H. CAVENDISH.* In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography.* Scribner, New York, vol. 3 (1971), pp. 155-159 — S. SCHAFFER: *CAVENDISH, Henry.* In: *The new Encyclopædia Britannica, Macropædia*. Benton & Hemingway, Chicago, vol. 3 (1974), pp. 1018-1020 — C. JUNGNICKEL and R. MCCORMMACH: *CAVENDISH, the experimental life.* Bucknell, Cranbury, NJ (1999) — R. MCCORMMACH: *Speculative truth: Henry CAVENDISH, natural philosophy, and the rise of modern theoretical science.* Oxford University Press, Oxford & New York (2004) — S. SCHAFFER: *CAVENDISH, Henry.* In: (H.C.G. MATTHEW, ed.) *Oxford dictionary of national biography*. Oxford University Press (2004), vol. 10, pp. 621-627 — F. SEITZ: *Henry CAVENDISH: the catalyst for the chemical revolution.* Proc. Am. Phil. Soc. **148**, No. 2, 151-179 (June 2004); http://www.aps-pub.com/proceedings/1482/480201.pdf.

PICTURE. Drawing probably by Charles ROSENBERG, after William ALEXANDER, early 19th century. © National Portrait Gallery, London, U.K.

NOTE. The vast bulk of CAVENDISH’s manuscript papers and correspondence has not been published; it is deposited in Chatsworth House (Derbyshire), in the possession of the duke of Devonshire.

CHALLIS, James (1803–1882)

▪ British clergyman, physicist, and astronomer



James CHALLIS was born at Braintree in Essex to John CHALLIS, a stone mason. Following his studies at Trinity College in Cambridge (1821–1825), he was elected Fellow of Trinity (1826) and resided there until ordained (1830). When George AIRY was elected Astronomer Royal (1835), he was succeeded by CHALLIS as Plumian Professor of astronomy and experimental philosophy (1836), and CHALLIS became director of the Cambridge Observatory (1836). In the first years of his professorship CHALLIS lectured on pneumatics, hydrodynamics, and geometrical and physical optics with special reference to the mathematical theories of light and sound. He published numerous papers on hydrodynamics, heat, light, the theory of colors, and astronomy. By invitation of the British Association for the Advancement of Science he wrote two reports of the current state of research on hydrodynamics. His *Report on the Present State of the Analytical Theory of Hydrostatics and Hydrodynamics* (1833) was the best known of his mathematical papers among contemporary scientists, which he followed with a substantial *Supplementary Report* (1836).

Attempting to treat the sound of finite longitudinal disturbance mathematically (1845–1851), he attacked his countrymen Samuel EARNSHAW, Sir George Biddell AIRY, and Sir George G. STOKES, later also crossing swords with them on other subjects. However, his disputes on the problem of how to correctly treat analytically *waves of finite amplitude*

(*i.e.*, of shock waves) kept discussions among early shock wave pioneers in full swing.

In the astronomy community CHALLIS soon became famous for his failure to discover the planet Neptune of which John C. ADAMS, another Cambridge astronomer, had already calculated the position and which was eventually discovered by Johann G. GALLE at the Berlin Observatory (1846) through Urban J. LEVERRIER's prediction. CHALLIS published some 60 papers reporting observations of comets and asteroids. Stress, due to arrears of reduction derided by AIRY, compelled him to give up his occupations at Cambridge Observatory (1861), but he retained the Plumian chair until his death.

CHALLIS contributed almost 250 mathematical, physical, and astronomical papers to scientific journals, partly as a co-author, and published in 12 volumes the *Astronomical Observations Made at the Observatory of Cambridge* (1832–1864), the chief result of his work. In his book *Notes on the Principles of Pure and Applied Calculations, and Applications of Mathematical Principles to Physics* (1869), a large volume of 700 pages, he also addressed applications of his hydrodynamical research. He was a Fellow of the Royal Astronomical Society (from 1836), a Fellow of the Royal Society of London (from 1848), and president of the Cambridge Philosophical Society (1845–1847).

Astronomers named a crater on the near side of the Moon after him.

ORIGINAL WORKS. *On the integration of the general equations of the motion of incompressible fluids.* Phil. Mag. **6** [II], 123-133 (1829) — *On the determination of the forms of the arbitrary functions which occur in the integrals of partial differential equations.* Ibid. **6** [II], 296-301 (1829) — *On the theory of the small vibratory motions of elastic fluids.* Trans. Cambr. Phil. Soc. **III**, 269-320 (1830) — *On the general equations of the motion of fluids, both incompressible and compressible, and on the pressure of fluids in motion.* Ibid. **III**, 383-416 (1830) — *On the theoretical determination of the motion of fluids.* Phil. Mag. **9** [II], 7-11 (1831) — *On the theory of the compressibility of the matter composing the nucleus of the Earth, as confirmed by what is known of the ellipticities of the planets.* Ibid. **10** [II], 200-204 (1831) — *Report on the present state of the analytical theory of hydrostatics and hydrodynamics.* Rept. Meet. Brit. Assoc. **3**, 131-151 (1833) — *Researches in the theory of the motion of fluids.* Trans. Cambr. Phil. Soc. **V**, 173-204 (1835) — *Supplementary report on the mathematical theory of fluids.* Rept. Meet. Brit. Assoc. **6**, 225-252 (1836) — *A general investigation of the differential equations applicable to the motion of fluids.* Trans. Cambr. Phil. Soc. **VII**, 371-396 (1842) — *On the necessity of three fundamental equations for the general analytical determination of the motion of fluids.* Phil. Mag. **26** [III], 425-431 (1845) — *Theoretical determination of the velocity of sound.* Ibid. **32** [III], 276-284 (1848) — *On the velocity of sound, in reply to the remarks of the Astronomer Royal.* Ibid. **32** [III], 494-499 (1848) — *Additional analytical considerations respecting the velocity of sound.* Ibid. **33** [III], 98-101 (1848) — *On the nature of aerial vibrations.* Ibid. **33** [III], 462-466 (1848) — *On the mathematical theory of aerial vibrations.* Ibid. **34** [III], 88-98 (1849) — *On the theoretical value of the velocity of sound, in reply to Mr. STOKES.* Ibid. **34** [III], 284-286 (1849) — *Determination of the velocity of sound on the principles of hydrodynamics.* Ibid. **34** [III], 353-366 (1849) — *On spherical waves in an elastic fluid, in reply to Mr. STOKES.* Ibid. **34** [III], 449-450 (1849) — *On some points relating to the theory of fluid motion.* Ibid. **34** [III], 512-520 (1849) — *On the modification of sounds by distance of propagation.* Ibid. **35** [III], 241-244 (1849) — *On the principles of hydrodynamics.* Ibid. **1** [IV], 26-38, 231-241, 477-478 (1851) — *On the theory of the velocity of sound.* Ibid. **1** [IV], 405-408 (1851) — *On the principles of hydrodynamics.* Ibid. **4** [IV], 438-450 (1852); Ibid. **5** [IV], 86-102 (1853) — *On some theorems in hydrodynamics.* Ibid. **6** [IV], 338-344 (1853) — *Theoretical considerations respecting the relation of pressure to density.* Ibid. **17** [IV], 401-404 (1859) — *On the general differential equations of hydrodynamics.* Ibid. **23** [IV], 436-445 (1862) — *On the principle of discontinuity in solutions of problems in the calculus of variations.* Ibid. **24** [IV], 196-201 (1862) — *Notes on the principles of pure and applied calculations, and applications of mathematical principles to physics.* Publ. privately (1869) — *A theory of the effects produced by fog and vapor in the atmosphere on the intensity of sound.* Ibid. **47** [IV], 277-281 (1874) — *On the mathematical principles of LAPLACE's theory of tides.* Ibid. **50** [IV], 544-548 (1875).

SECONDARY LITERATURE. J.W.L.G. [J.W.L. GLAISHER]: *James CHALLIS.* Month. Not. Roy. Astron. Soc. **43**, 160-179 (1883) — O.J. EGGEN: *J. CHALLIS.* In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography.* Scribner, New York, vol. 3 (1971), pp. 186-187 — M. YAMALIDOU: *Molecular ideas in hydrodynamics.* Ann. Sci. **55**, 369-400 (1998) — A.M. CLERKE and D.B. WILSON: *CHALLIS, James.* In: (H.C.G. MATTHEW, ed.) *Oxford dictionary of national biography.* Oxford University Press, Oxford (2004), vol. 10, pp. 859-862.

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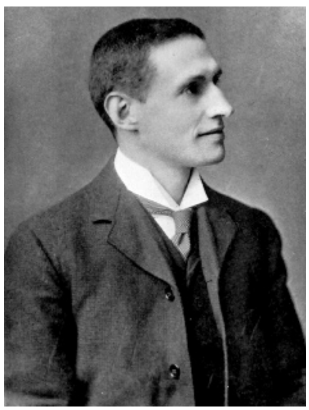
CHAPMAN, David Leonard (1869–1958)

▪ British physical chemist, cofounder of the first theory on detonation



Born in Wells, Norfolk, David L. CHAPMAN's father, David CHAPMAN, was a builder in Manchester. After his education at Manchester Grammar School he won an Open Exhibition at Christ Church, Oxford, and was placed in the First Class of the Final Honor School of Natural Science (1893), being awarded a Second Class for Physics. When he took up a post as science master at Gigglewick (1894), he was soon picked by Harold B. DIXON, a professor of chemistry, to join his staff at Owens College, University of Man-

chester (1897–1907). In his Bakerian Lecture (1893), DIXON had reported about his observation on the velocities of explosion in gases, to which Prof. Arthur SCHUSTER made the comment that on either side of the explosive wave, later to be called the "detonation wave," the exploded and unexploded gases might have uniform densities and velocities. Based upon SCHUSTER's hypothesis and DIXON's experimental data of detonation velocities, CHAPMAN theoretically investigated in his paper *The Rate of Explosions in Gases* (1899) the phenomenon of detonation on a rational basis. First applying Bernhard RIEMANN's formula to both sides of the detonation front, which separates two chemically different states, he made the important assumption that the detonation moves steadily and – consistent with the condition of maximum entropy – possesses a minimum velocity, the so-called "Chapman equation." With data thus obtained, he was able to calculate the explosion velocities for some 40 other mixtures. Independently, a very similar assumption was later made in France by Emile JOUGUET, the so-called "Chapman-Jouguet (CJ) hypothesis" and the conditions behind an advancing explosive wave are now referred to as the Chapman-Jouguet (CJ) state (1899–1905). Detonations with fronts advancing at sonic speeds – so-called "Chapman-Jouguet detonations" – are the most common.

After his famous studies on explosives at Owens College, CHAPMAN accepted a Fellowship at Jesus College, Oxford, and began to investigate the kinetics of chemical reactions in more detail, partly with the assistance of his wife and C.H. BURGESS, two chemists. These fundamental studies (1899–1937), including also photochemically induced explosive reactions in gases, opened a new field of research and stimulated Max BODENSTEIN and Walther H. NERNST in Germany on their concept of chain reactions. Together with his students CHAPMAN published over 40 papers, reporting on studies of the decomposition of water vapor by electric spark (1902), retarding reaction effects (1909), and photochemical reactions of gases subjected to ultraviolet radiation and their dependency on light intensity, here particularly focusing on the puzzling chlorine-hydrogen reaction (1909–1933). As a forerunner of modern reaction kinetics he was already engaged in discussions about problems of the decomposition of ozone (1910–1911) and the role of metals in the catalysis of gases (1929–1936). CHAPMAN remained at Jesus College as College tutor in charge of the laboratories until his retirement (1944).

He was a Fellow of the Royal Society (from 1913) and served on its Council (1934–1936).

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PICTURE. Taken in 1920. Courtesy Manchester Archives and Local Studies, Manchester, U.K.

CORIOLIS, Gaspard Gustave DE (1792–1843)

▪ French mathematical physicist and engineer

G. Gustave DE CORIOLIS was born in Paris to Jean-Baptiste-Elzéar DE CORIOLIS, an officer of king Louis XVI. He was brought up in Nancy to where his family had taken refuge and where his father became an industrialist. He entered the Ecole Polytechnique (1810), and after graduation at the Ecole des Ponts et Chaussées (1813) he served in its Corps of Engineers, spending several years in the Dépt. Meurthe-et-Moselle and in the Vosges Mountains. Recommended by the

eminent mathematician Augustin-Louis CAUCHY, he became in 1816 tutor in mathematical analysis at the Ecole Polytechnique. In 1829, he accepted the position of chair of mechanics at the newly founded Ecole Centrale des Arts et Manufactures in Paris, and in 1832 assisted Louis NAVIER in applied mechanics at the Ecole des Ponts et Chaussées where he succeeded him in 1836. CORIOLIS ended his teaching at the Ecole Polytechnique in 1838 and succeeded Pierre L. DULONG as director of studies in the same school.

CORIOLIS' whole life, although overshadowed by a delicate constitution, was devoted to research and methods of teaching mechanics, which, together with the mathematician Jean PONCELET, he successfully reformed. Inspired by the writings of Nicolas CARNOT, he worked out his theory of machines, which, addressing the "economy" of mechanical power and introducing the important term *travail* ("work"), was published in his first book *Du calcul de l'effet des machines* (1829); its second edition was published posthumously under the new title *Traité de Mécanique* (1844). In this important work CORIOLIS proposed a unit of measurement of work, the *dynamode* (corresponding to 1,000 kg-meters). While this term was not adopted by his contemporaries, his term *force vive* ("kinetic energy") for one half the product mv^2 was generally accepted. Today CORIOLIS is best remembered for the composed centrifugal force [French *force centrifuge composée*], the so-called "Coriolis force," which first appeared in the paper *Sur les équations du mouvement relatif des systèmes de corps* (1835). In this paper he showed that the Laws of Motion could be used in a rotating frame of reference if an extra force is added to the equations of motion *(Coriolis theorem)*. The so-called "Coriolis effect" denotes the effect of the Coriolis force to deviate a moving body perpendicular to its velocity vector. Enunciated by him regarding relative motions, it has found numerous applications, particularly in the case of motion on, above, or below the surface of the Earth, for example (1) the deviation toward the east of falling bodies, an observation that had already been cited by Robert HOOKE and Sir Isaac NEWTON as a possible experimental proof of the Earth's rotation; (2) the tendency of an ocean current, a wind system, or an artillery round to drift sideways from its course; and (3) the apparent rotation of the plane of vibration of a Foucault pendulum. In 1873, the French mechanics professor Henry A. RÉSAL used the Coriolis theorem to calculate the vibrational motions of molecules.

In the early 1830s, CORIOLIS began to tackle the difficult task of analytically investigating in the game of billiards the various modes of collision and the influence of friction. In the same year in which he published his Coriolis effect, CORIOLIS also presented his famous mathematical theory of billiards, certainly the most prominent and spectacular example of elastic collision. After watching for a while the famous French player Captain François MINGAUD who first introduced new, highly surprising *effets* ("side shots") into the game, he worked out an analytical solution to these complicated collision processes, thereby considering not only the translational and rotational kinetic energy of the hit ball but also friction effects between ball and cloth, and modifications of the ball trajectory in the special case of side shots. CORIOLIS himself considered his contribution to billiards as his greatest work, but his fame from mathematically analyzing billiards was soon surpassed by his *Coriolis effect*.

In his book on classical mechanics, *Traité de la mécanique des corps solides et du calcul de l'effet des machines* (1844), which was published posthumously, he introduced a moving frame of reference that allows one to study the relative motions of three bodies, known as the "three-body problem" – a particularly challenging task that occupied generations of mathematicians.

CORIOLIS was a member of the French Academy at Paris (from 1836). The *Coriolis Data Center* is a French contribution to operational oceanography. In honor of his lasting contributions to theoretical and applied mechanics, a French oceanographic research vessel was named for him. Its scientific team discovered the *Coriolis Troughs* which, located in the south of the New Hebrides, are one of the world's most youthful, magmatically-active back arc basins. The *Coriolis parameter* is a measure of planetary rotation as a function of latitude.

A crater on the far side of the Moon is also named after him.

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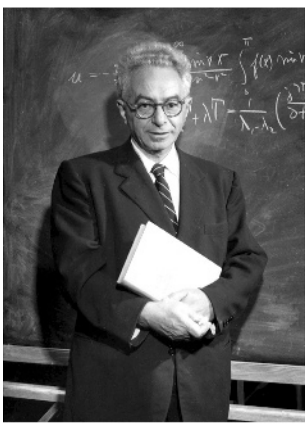
COURANT, Richard (1888–1972)

▪ German-born U.S. mathematician and fluid dynamicist



Richard COURANT was born at Lublinitz in Upper Silesia (now Lubliniec, southern Poland) to Siegmund COURANT, an unsuccessful Jewish businessman. He attended the gymnasium in Breslau and studied mathematics at the Universities of Breslau (1906), Zürich (1907), and Göttingen (1908–1910). He began to teach mathematics as *Privatdozent* (university lecturer) at Göttingen (1910–1920), where he succeeded Prof. Christian Felix KLEIN, an eminent German mathematician. After serving in the German Army (1914–1918) and becoming a highly decorated officer, he resumed his teaching activity in Göttingen and became professor of mathematics and director of the Mathematical Institute at the University of Göttingen (1920–1933). In a joint study with Kurt O. FRIEDRICHS and Hans LÉWY, two German mathematicians, he discovered the conditional stability of the difference-equation integration method for partial differential equations, the so-called "Courant-Friedrichs-Léwy condition" (1928), which, rediscovered in the 1940s by John VON NEUMANN, who called it the "Courant criterion," became important in the pioneering era of digital computers for the numerical simulation of hydrodynamic shocks. The "Courant number," the ratio of a time step to a cell residence time, representing a stability factor, is named for him. Due to increasing political pressure, COURANT emigrated with his family first to the United Kingdom (1933) and then to the United States, where he became professor and head (1936–1958) of the department of mathematics at New York University (NYU), New York City.

In 1943, COURANT first developed Finite Element Analysis (FEA) utilizing the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. During World War II, he got involved in shock waves and associated interaction phenomena. COURANT also directed theoretical studies of pulsejet engines (1944), which became a subject of immediate interest due to the increasing employment of the German Schmidt tube in the first cruise missile, the V1. Based on the Göttingen approach, he established at NYU the Institute for Mathematics and Mechanics and became its first director (1947–1958). Together with Kurt O. FRIEDRICHS, his former student from Göttingen, and James J. STOKER, an American originally trained in engineering, he transformed his small institute into one of the world's largest institutes of applied mathematics. The mathematical center was renamed the Institute of Mathematical Sciences (1953), a name that was also adopted by other leading mathematical institutions. In 1958, the institute was renamed the Courant Institute of Mathematical Sciences (CIMS) and became a center for research and advanced training in mathematics and computer science. It is attached to New York University and is located in Greenwich Village in lower Manhattan.

After his retirement (1958) COURANT served as consultant to both governmental agencies and private industry and was also active on various scientific commissions. Throughout his life he was devoted to the applicability of pure mathe-

matics, particularly to quantum mechanics and gas dynamics. He is also credited with paving the way for the use of electronic computers in applied science. Courant worked on mathematical analysis and physics, the theory of functions, and the calculus of variations. He wrote several best-sellers on mathematics such as the book he cowrote with Herbert Robbins, *What is Mathematics?* (1941). In the gas dynamics community he is best known for his book *Supersonic Flow and Shock Waves* (1948), which he cowrote with Friedrichs.

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Cranz, Carl Julius (1858–1945)

▪ German physicist, dean of German ballistics

Carl J. Cranz was born at Hohebach, Oberamt Künzelsau, in Württemberg, to a Protestant minister. Initially his family intended for him to also embark upon a theological career, and in 1877 he began to study theology and philosophy at Tübingen University. But in 1879 he left Tübingen and began to study physics at the Friedrich-Wilhelms-Universität (since 1945 Humboldt-Universität) in Berlin under the famous physicists Gustav Kirchhoff and Hermann von Helmholtz and the electrophysiologist Emil Dubois-Reymond. Returning to Tübingen in 1880, he continued his study of mathematics under the physicist Friedrich Eduard Reusch and the mathematician Paul Dubois-Reymond. Under the latter he took his doctorate with a thesis on the ideal shape of a projectile to minimize deviations (1883), a subject that he returned to in later years. In the period 1882 to 1883, he passed his examination for professorship at the TH Stuttgart, where he became an instructor of mathematics and physics. Besides teaching in Stuttgart at the Friedrich-Eugen-Lyceum (1882–1903), a secondary school for girls, he started various research activities, comprising mathematical, ballistic, physical, and geophysical problems.

Owing to his expertise in ballistics he was offered a chair at the Technische Hochschule (TH) in Berlin-Charlottenburg and became first director of the Militärtechnische Akademie (1903–1918), which was founded in 1903 close to the campus of the TH Berlin. After World War I, the military academy was shut down, but it reopened in 1919 under the demilitarized designation "Institut für Technische Physik" with Cranz as its director (1919–1935). It was shut down permanently at the end of World War II.

His contributions are manifold: (1) measurement of projectile drag at supersonic speed; (2) barrel vibration and flow phenomena at the muzzle of a fired gun; (3) generation and propagation of shock waves in gaseous, liquid, and solid matter; (4) interaction of shock waves with objects; (5) graphical methods for use in interior and exterior ballistics; (6) similarity laws in ballistics; and (7) development of high-speed diagnostic instrumentation. His most prominent disciple was Hubert Schardin, who was his close assistant for 10 years (1926–1936) and with whom he went to Nanking to establish the first ballistic research institute in China (1934–1936). Together with Schardin he developed in the 1930s the so-called "Cranz-Schardin multiple spark camera," which allowed one to optically resolve high-speed events at frame rates up to some 10^6/s. Their principle was also used

by others to study self-luminous phenomena using an array of flash X-ray tubes {TSUKERMAN & MANAKOWA ⇨1957}.

For 62 years CRANZ contributed largely to theoretical ballistics and methods of high-speed diagnostics related to solving problems in ballistic research. During his life he saw great changes in ballistics, ranging from classical ballistics of firearms and the development of huge guns (*e.g.*, *Paris-geschütz*, *Dicke Bertha*, *Dora*) up to the development and immediate applications of new types of weapons that dramatically changed military strategy down to our own times, such as cruise missiles (V1) and ballistic rocketry (A-4 or V2, and A-4b). Shortly after World War II, CRANZ died in Esslingen, Germany at the age of 87.

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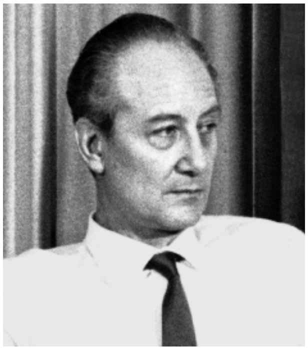
PICTURE. Reprinted from Z. Tech. Phys. **9**, 1 (1928).

CROCCO, Luigi Mario (1909–1986)

▪ Italian-born U.S. aeronautical engineer



Luigi M. CROCCO was born in Palermo, Sicily to General Gaetano Arturo CROCCO (1877–1968), a renowned Italian pioneer of aeronautics who later became professor at the School of Aeronautical Engineering of the University of Rome. At this school Luigi CROCCO studied mechanical engineering. Simultaneously with his studies, together with his father he conducted research in the field of rocketry (1927–1931), particularly to determine the combustion laws of double-base powder propellants (1927–1929) and liquid propellants (1929–1931). In addition, he was very attracted to the aerodynamic theory of high speed, a field that he pursued throughout his entire career. As an assistant professor of aviation engines at the School of Aeronautical Engineering of the University of Rome (1937), he became increasingly attracted to high-speed aerodynamics and in 1939 was appointed Chair of Aviation Engines (1939–1949).

His first publication (1931) was on high-speed boundary layers, and his approach led to what later became known as the "Crocco energy integral." Following graduation as a mechanical engineer (1931) and military service (1931–1933), he continued his rocket research and became involved in non-atmospheric propulsion. He also reviewed the characteristics of different types of supersonic wind tunnels of that time, later renowned as *CROCCO's bible* (1935). His other major contributions were the *Crocco vorticity law* (1937) and studies of compressibility effects of laminar boundary layers. In 1939, he proposed a boundary-layer equation (*Crocco equation*) in a form that could be converted into an integral equation for constant pressure flow, and six years later he showed that the integral equation could be conveniently solved by iteration. Later his research focused on liquid monopropellants, mainly on mononitromethane, which does not require the use of air as an oxidizer and, therefore, appeared to be a promising propellant for underwater and stratospheric propulsion (1933–1937).

During World War II his scientific activities shifted toward aviation motors and jet engines. In a joint research project with the French War Ministry he resumed his studies on the use of nitromethane in rocket motors (1947). In 1949, Harry F. GUGGENHEIM created two jet propulsion centers, one at CalTech in Pasadena and one at Princeton University. CROCCO accepted an invitation to join the staff at the Princeton center as a visiting professor. He became a member of the newly founded Department of Aeronautical Engineering at Princeton University (1949–1970) and Goddard Professor to supervise the Guggenheim Jet Propulsion Center. Besides his teaching duties he was deeply involved in the investigation of combustion instability in liquid-propellant rocket motors and their elimination. In particular, he provided the first theoretical explanations of high-frequency instability, then a serious problem and of immediate practical interest in many NASA rocket-development programs. Returning to Europe in 1970, he taught at the University of Rome, at the Ecole Polytechnique in Paris, and worked as a consultant to ONERA. He retired in 1978.

CROCCO was a member of various national academies. He received the Pendray Award (1965), the Wild Award (1969), and the Columbus International Prize and Gold Medal (1973). His high reputation and great intellect are best reflected by the fact that he was fluent in six languages and sought out as a consultant by major aeronautical and aerospace companies and governmental agencies throughout the Western World.

The *Luigi Crocco Teaching Prize*, a cash prize, was first awarded by the Dept. of Mechanical and Aerospace Engineering (MAE) of Princeton University to a student in the fall of 1988. The Cluster for Research on Complex Computations (CROCCO) at MAE was named for Luigi CROCCO, because he was among the first in his generation to seriously devote efforts on numerical techniques to solving practical and complex fluid flows. The *Luigi Crocco Colloquia* bring outstanding engineers and scientists from other research centers to Princeton throughout the year and are considered an important feature of the department's graduate program.

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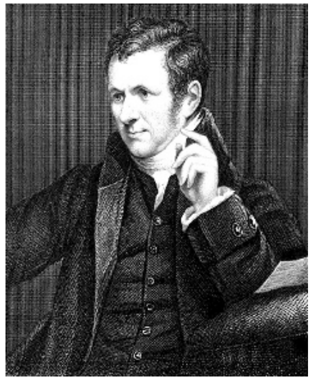
PICTURE. Courtesy Prof. Irvin GLASSMAN, Dept. of Mechanical & Aerospace Engineering, Princeton University, NJ.

DAVY, Sir Humphry (1778–1829); from 1818 Baronet

▪ English chemist and inventor



Sir Humphry DAVY, born at Penzance in Cornwall, was the eldest son of Robert DAVY, a woodcarver. His first experience with chemistry was when he made fireworks with his sister. During his apprenticeship to an apothecary-surgeon (1795–1798) he discovered his interest in chemistry and drew up a formidable program of self-education. His scientific career began when he was appointed superintendent in Thomas BEDDOES' Pneumatic Institution at Clifton. Here he became interested in gases and discovered in self-tests the anesthetic properties of nitrous oxide. His book on this specific gas, entitled *Researches, Chemical and Philosophical…* (1799), made his reputation. He was appointed to a lectureship at the Royal Institution in London (1801) and became professor of chemistry (1802). His lectures were famous for their brilliant presentation. He employed Michael FARADAY as amanuensis, and on DAVY's recommendation FARADAY was given a job at the Royal Institution of Great Britain (1812).

His contributions to both organic and inorganic chemistry are enormous; prominent examples include (1) experimental evidence that oxygen and hydrogen are the only product of the electrolysis of pure water (1800); (2) improvement of the Volta cell by making piles with charcoal replacing one metal, and with two fluids and one metal (1801–1802); (3) observations on the processes of tanning and lectures on the chemistry of this subject (1801); (4) discovery of boron, hydrogen telluride, and hydrogen phosphide (or phosphine) [PH_3], and isolation of the metals sodium and potassium from their compounds by means of electricity (1807); (5) analysis of the alkaline earth metals and isolation of magnesium, calcium, strontium, and barium (1808); (6) experimental evidence that chlorine is an element and hydrochloric acid free of oxygen (1807); (7) investigations on nitrogen trichloride [NCl_3] and its detonating properties (1812–1813); (8) experiments on the combustion of the diamond (1814–1818); (9) researches on the preservation of metals by electrochemical means (1824–1825); and (10) studies on the nature of the electrical action of living animals (1829) such as the organs of the electric ray [*Torpedinidae*] and the electric eel [*Gymnotidae*].

Throughout his life DAVY was also interested in geology and also studied volcanism using Vesuvius as an example (1827). He suggested that volcanoes might have a core of molten alkali metal, acted on by water to cause eruption. But an analysis of lava did not confirm his hypothesis, and he eventually dropped it.

Spurred by a number of disasters in coal mines, he turned his attention to the problem of explosive firedamp (1813). Analyzing gas samples from English coal mines, he concluded that methane is the main constituent and confirmed previous observations that this gas could be ignited only at a high temperature. He constructed a lamp in which the air intake and the chimney were exposed to narrow tubes and

found that they did not explode firedamp. Later he found that wire gauze surrounding the flame was equally efficient – his famous *Davy lamp* (1815). He did not ask for a patent and in 1816 wrote, "I never thought of such a thing, my sole object was to serve the cause of humanity, and if I succeeded I am amply rewarded in the gratifying of having done so." He was the first to observe the rate at which an explosion of gases was propagated in a tube, and he also made the first rough experiment on the temperature reached in a gaseous explosion (1816).

DAVY's safety lamp proved extremely useful. From miners he received numerous letters of thanks and from the Association of Coal Owners a service of plates valued at 2,500 pounds, which was eventually sold to found the *Davy Medal* – an award conferred annually by the Royal Society of London, "for an outstanding important recent discovery in any branch of chemistry." When first awarded in 1877, the medal was jointly presented to Robert BUNSEN and Gustav KIRCHHOFF for their researches and discoveries in spectrum analysis.

DAVY was knighted (1812) and made a baronet (1818). He was admitted to be a Fellow of the Royal Society of London (1803), elected secretary (1807), and later became its president (1820–1827), then succeeding the physician and scientist William H. WOLLASTON. After spending the winter of 1828/1829 in Italy inquiring into volcanic action, he had a stroke that resulted in paralysis on his right side and during his return to England died in Geneva, Switzerland. DAVY received the Copley Medal (1805) for his researches on voltaic cells, tanning, and mineral analysis, the Napoleon Prize for his researches on electrolysis (1807), the Rumford Medals (gold and silver) for his researches on flame (1816), and the Royal Medal for his ideas on electrochemistry (1827). DAVY was a cofounder of the Geological Society of London (founded in 1807), the oldest association of its kind in the world.

Astronomers named a crater on the near side of the Moon after him.

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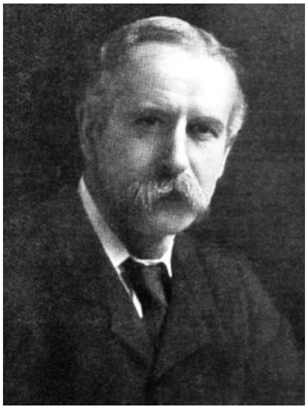
PICTURE. Engraving after a painting by James LONSDALE (after 1800). In the public domain, taken from Wikipedia, the free encyclopedia; http://en.wikipedia.org/wiki/Image:Sir_Humphry_Davy.jpg.

NOTE. *The Royal Society: The Davy Medal (1877). The Davy archive winners 1899–2005*; http://www.royalsoc.ac.uk/page.asp?tip=1&id=1754.

DIXON, Harold Baily (1852–1930)

▪ British chemist, founder of the Manchester School of Combustion Research

Harold B. DIXON was born in London to William Hepworth DIXON, a traveler, historical writer, and editor of the *Athenaeum,* a literary magazine published in London (1828–1921). Initially he intended to follow a literary career and entered Christ Church College at Oxford (1870); however, he transferred from classical studies to natural science and



after graduation was elected to a fellowship at Trinity College, Cambridge. It was at the instigation of A. Vernon HARCOURT, a reader in chemistry at Christ Church, that DIXON commenced studying chemistry (1873) and later, in particular, gaseous explosions (1876). He was a lecturer at Balliol College and Trinity College, Cambridge, and in 1886 became professor of chemistry at Owens College of Victoria University, Manchester, where he stayed until his retirement. There he founded his Manchester School of Combustion Research. His research assistants were Harry Wood SMITH and George S. TURPIN (1888), then William Arthur BONE and Bevan LEAN (1891), Edward Halford STRANGE and Edward GRAHAM (1894), Edward John RUSSELL (1896), and later R.H. JONES and L. BOWER, all of whom collaborated with him during the period 1888–1903 in experimental work on the ignition and detonation properties of gaseous mixtures. In addition, he had a number of students working on this subject along the same lines as he – the most prominent being David Leonard CHAPMAN {⇨1899}, cofounder of the theory of detonation, and Colin CAMPBELL, codiscoverer of "spinning detonation" {CAMPBELL and WOODHEAD ⇨1926/1927}.

DIXON's combustion research followed three principal lines. (1) In his early Oxford researches on gaseous explosions he demonstrated that purified and dried explosive gases could not be ignited by an electric spark but detonated when a small amount of water was added (1877–1880), thus proving – in opposition to the German chemist Robert W. BUNSEN {⇨1853} – the validity of BERTHOLLET's Law of Mass Action for chemical explosion. (2) In 1880 he began studying the rate of gaseous explosions, instigated by Prof. Vernon HARCOURT on the occasion of a disastrous explosion of a gas main line that happened in London in the same year. He photographed the flame movements in an explosion using a streak method very similar to that applied by the French chemists François Ernest MALLARD and Henri Louis LE CHÂTELIER (1880–1883) and the German physicists Arthur VON OETTINGEN and Arnold VON GERNET (1888), but refining the technique and improving the resolution (1890–1900). (3) DIXON discovered the backward traveling "retonation wave" and also observed "reflection waves" arising when a detonation wave is either reflected at the closed end of a tube or on passing a restriction in it. (4) He first determined the ignition temperatures of explosive gaseous media, particularly when they contain small amounts of impurities (1903–1930). Thus he found that the presence of small quantities of oxide of nitrogen lowers, whereas that of iodine vapors materially raises, the ignition temperatures.

DIXON was elected president of the Manchester Literary and Philosophical Society (1907–1909) and the Chemical Society of London (1909–1911). In his last paper published in 1929 in the journal *Nature* (London), one year before his death, DIXON proudly wrote: "If the highest reward a teacher can reach is to start a school which will carry on his lines of research, improving his technique, extending his data and enlarging his horizon, I may well claim that my lines have fallen on pleasant and fruitful places."

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PICTURE. Courtesy Library and Information Centre, Royal Society of Chemistry, Cambridge, U.K.

DOPPLER, Christian Andreas (1803–1853)

▪ Austrian physicist

Christian A. DOPPLER, son of noted stonemason Johann E. DOPPLER, was born in Salzburg, Austro-Hungarian Empire. His poor health, however, did not allow him to follow his father's profession. Because of his great talent in mathematics he attended the Polytechnic Institute in Vienna (1822–1825), where he was employed later as a mathematical assistant (1829–1833). In Prague he became professor of mathematics and accounting at the State Secondary School (1835), followed by a professorship of elementary mathematics and geometry at the Technical State Academy (1841). For a short time, he stayed at the Mining Academy of Schemnitz (now Banská Štiavnica, Slovakia) as *Bergrat* and professor of mathematics, physics, and mechanics (1847–1850). Forced by political turbulence, he returned to Vienna and became the first director of the new Physical Institute (1850–1853) and full professor of experimental physics at the Royal Imperial University of Vienna. Suffering from a lung disease since his period at Prague, he traveled in November 1852 to Venice in the hope that the warmer climate would bring about some improvement. He died there in March 1853 at the age of 49.

His scientific fame is based on his *Doppler effect* (1842), an apparent shift in the frequency of waves received by an observer, depending on the relative motion between the observer and the source of waves. DOPPLER, trying to explain the colored light of double stars, correctly recognized the importance of his *Doppler principle*, in acoustics, optics, and astronomy. The Dutch meteorologist Christophorus BUYS-BALLOT first proved the correctness of the Doppler effect in a material medium by acoustic experiments. From the red shift of spectroscopic lines in the light from the stars, the British astronomer William HUGGINS first determined the velocities of these stars relative to our Sun (1868). More than 60 years later, the U.S. astronomer Edwin P. HUBBLE, based on the Doppler effect, concluded that galaxies are receding from us with relative velocities that increase in proportion to the distance (1929).

To illustrate the consequences of his principle in acoustics, DOPPLER assumed explosion-like disturbances moving on a straight or curved line with a velocity slower, equal to, or faster than the sound velocity of the surrounding medium (1846). For disturbances propagating along a straight line with a constant supersonic velocity u in a medium of sound velocity a, DOPPLER, using HUYGENS' principle of wave propagation, constructed the envelopes of all elementary disturbances, which resulted in a straight cone geometry with a half cone angle $\alpha = \arcsin a/u$. His supersonic wave model, later taken up by Ernst MACH to explain his head wave phenomenon of supersonic shots (1887), was named *Mach cone* by 20th-century scientists, although credit should have been given to DOPPLER rather than to MACH. In 1846, DOPPLER, using HUYGENS' principle of constructing wave fronts by sources of secondary spherical wavelets, treated also two cases of disturbances moving with accelerated and decelerated supersonic velocities along a straight line, which resulted in a concave and convex cone geometry, respectively. DOPPLER's third example describes a supersonic disturbance moving on a circle that, seen from the center of rotation, results in a concave shaped head wave geometry. This case became of particular interest for aircraft designers at the end of World War I when propeller tips began to exceed sound velocity.

Other examples of applications of the Doppler effect are in high-speed diagnostics (*e.g.*, laser anemometry, laser velocimetry), meteorology, radar, navigation, medical ultrasonic diagnostics, and Mößbauer-effect studies.

The *Christian-Doppler-Fonds* (Christian-Doppler Foundation) and the *Doppler-Institut für medizinische Wissenschaft und Technologie* (Christian-Doppler-Institute for Medical Science and Technology), both located in Salzburg, Austria,

support scientific research and publications related to the Doppler effect.

A crater on the far side of the Moon and a minor planet (asteroid 3905 DOPPLER) are named for him.

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PICTURE. This daguerreotype, taken in 1844, is the only one of DOPPLER that has survived. Courtesy Dr. Peter M. SCHUSTER (Pöllauberg, Austria), who discovered it in the personal property of Mrs. Dorothea MERSTALLINGER, DOPPLER's great-granddaughter. The picture is now kept at the Archives of the Christian Doppler Foundation in Salzburg, Austria.

NOTE. In some biographies DOPPLER's first names were given incorrectly as Johann Christian rather than Christian Andreas; *see* SCHUSTER's book *Moving the stars – Christian DOPPLER* (cf. above), pp. 18-19.

DÖRING, Werner Siegfried (1911–)

▪ German theoretical physicist, cofounder of modern detonation theory

Werner S. DÖRING was born in Berlin-Tegel to chief engineer Gebhard DÖRING and studied technical physics at the TH Stuttgart (1930–1932) and the TH Berlin (1933–1935). Under the supervision of Prof. Richard A. BECKER, a theoretical physicist at the TH Berlin, he received his Ph.D. with an experimental study on the temperature dependency of magnetostriction in nickel (1936). He wrote his *Habilitationsschrift* (habilitation thesis) on reversible processes in magnetic materials with small inner stress which qualified him for being admitted as a university professor. In 1939, he became *Privatdozent* (university lecturer) at the University of Göttingen and in 1942 associate professor at the Reichsuniversität Posen. After World War II, he served as lecturer (*Diätendozentur*) of theoretical physics at the TH Braunschweig (1946–1949). In this period he also did research for a short time in France at the ISL, Saint-Louis, and in Switzerland at the Zurich IBM Research Laboratories. Thereafter, he became full professor and taught theoretical physics at the University of Gießen (1949–1963). In 1963, he was called to the chair of the Theoretical Physics Department at the University of Hamburg, where he stayed until his retirement (1976).

His work contributed mainly to three fields: He dedicated much of his research efforts to the study of magnetic properties of matter, particularly of ferromagnetism and micro magnetism. In 1941, at a secret workshop held in Berlin, DÖRING first reported on a theory of how to determine the pressure distribution behind a detonating explosive, thereby developing the concept that a detonation wave can be described as a shock wave immediately followed by a flame, whereby the reaction rate is finite, a hypothesis suggested independently by Yakov B. ZEL'DOVICH (1940) in the Soviet Union and John VON NEUMANN (1942) in the United States. This so-called "Zel'dovich-von Neumann-Döring (ZND) model" – actually named correctly the ZDN model – stimulated numerous researchers to study the influence of finite reaction rates

on the structure of a 1-D detonation wave in a compressible medium. His interests in ferromagnetism and detonation were already stimulated in the late 1930s by his previous cooperation with Prof. R.A. BECKER. DÖRING also developed a theory of germ formation in supersaturated phases.

Besides teaching physics to students, DÖRING dedicated much of his time to training physics teachers for teaching at the high-school level. He wrote several textbooks on special fields of physics such as the electromagnetic field (1955), thermodynamics (1956), statistical mechanics (1957), theoretical physics (1960), ferromagnetism (1966), atomic physics, and quantum mechanics (1973) and is the author of several related handbook articles.

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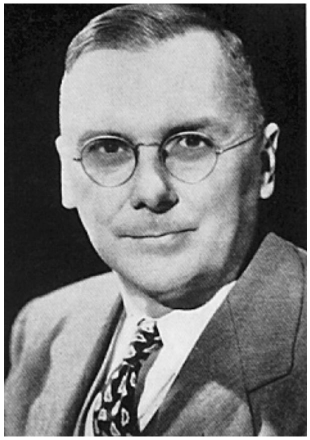
PICTURE. Courtesy Archives of the University of Hamburg, Germany.

NOTE. DÖRING's classic report "*Beiträge zur Theorie der Detonation*" [Forschungsbericht Nr. 1939 (1944)], in which he specified his detonation theory, was classified during World War II and distributed only in very limited numbers. For example, one copy is kept at the Archives of the Deutsches Museum, Munich. DÖRING's personal copy, transferred by him to the author in Nov. 2002, is now kept at EMI library, Freiburg.

DRYDEN, Hugh Latimer (1898–1965)

▪ U.S. physicist and aerodynamicist, and administrator



Hugh L. DRYDEN was born in Pocomoke City, MD, to Samuel Isaac DRYDEN, a schoolteacher who ran a general store. He obtained his early education in the Baltimore public schools. He entered Johns Hopkins University, Baltimore, MD at the early age of 15. While still working on his Ph.D. under the supervision of Joseph S. AMES, a chairman of NACA, he began his aeronautical research at the newly installed wind tunnel facility of the National Bureau of Standards (NBS) (1918–1944). After receiving his Ph.D. in physics, with a dissertation entitled *Air Forces on Circular Cylinders* (1919), he became technical director of the aerodynamics division at NBS (1920), where he began his research on boundary layer control and the origin of turbulence. He also developed methods of accurately measuring turbulence in wind tunnels, contributed to the design of wind tunnels with very low turbulence, and studied the influence of turbulence on aerodynamic forces imposed upon models tested in wind tunnels at high speeds. During World War II, DRYDEN and his associates Galen B. SCHUBAUER and Harold K. SKRAMSTAD successfully verified experimentally previous theoretical predictions on the onset of instability made by Hermann SCHLICHTING and Walter TOLLMIEN, who had observed in the early 1930s that the transition to turbulence is initiated and continuously generated at a multiplicity of spots on the surface of an object exposed to a high-speed flow at the upstream edge. During World War II, he also headed the development of the Bat air-o-surface missile, which earned him the Presidential Certificate of Merit.

In 1947, he became director of aeronautical research of the National Advisory Committee on Aeronautics (NACA). Two years later he was appointed director of NACA, the highest career position of this agency, which he held until 1958 when he became deputy administrator of the National Aeronautics and Space Administration (NASA). In the period 1954 to 1957, he was chairman of the Air Force-Navy-NACA Research Airplane Committee, which was installed in order to

supervise the design and production of the X-15. This hypersonic plane, which shortly before DRYDEN's death was the first to reach Mach 6 and an altitude of nearly 70 miles (112 km), provided most worthwhile full-scale flight data at hypersonic speeds and high altitudes for future spacecraft. DRYDEN also played a key role in other aircraft testing, such as the X-1, D-558, X-3, X-4, X-5, and the XB-70.

In 1958, he was named deputy administrator of NASA and participated in the organization of the projects of manned space flights of Mercury, Gemini, and Apollo and in the decision to mount a lunar exploration mission. In 1959, he was appointed one of two men to assist Ambassador Henry Cabot LODGE JR. at the first meeting of the United Nations Committee on the Peaceful Uses of Outer Space (1959). Together with Theodore VON KÁRMÁN he edited the series *Advances in Applied Mechanics* (vols. IV–IX, 1956–1966), published by Academic Press, which contains review articles of internationally renowned experts in the field of fluid mechanics and shock waves. DRYDEN's numerous contributions to aeronautics as well as his great ability in organizing international cooperation in aeronautical and aerospace research were acknowledged by many national and international organizations, such as by awarding him 16 honorary degrees. DRYDEN was also recipient of the Daniel Guggenheim Medal (1950), and the Robert H. Goddard Memorial Trophy (1964) which he received together with James E. WEBB for "representing the Gemini Program teams which significantly advanced human experience in space flight," and the National Medal of Science (1966). The greatest honor came posthumously in 1976 when NASA renamed its Flight Research Center in Edwards, CA the *NASA Hugh L. Dryden Flight Research Center (NASA-DFRC)*. The *Dryden Flow Visualization Facility* at NASA-DFRC, a water tunnel facility that became operational in 1983, is used primarily as a low-cost diagnostic tool for visualizing and analyzing vortical flows on aircraft and other shapes at high incident angles. The *AIAA Dryden Lectureship in Research* was named in honor of him in 1967, succeeding the Research Award established in 1960. The lecture emphasizes the great importance of basic research to advancements in aeronautics and astronautics and is a salute to research scientists and engineers.

A crater on the far side of the Moon is also named for him.

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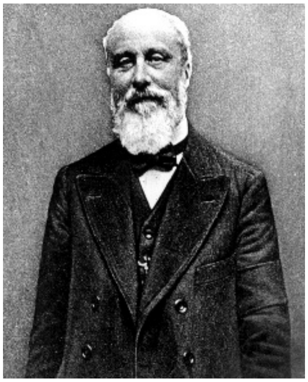
PICTURE. Taken on October 28, 1958. Courtesy NASA Dryden Flight Research Center, Edwards, CA (image No. E4248).

DUHEM, Pierre Maurice Marie (1861–1916)

▪ French physicist and philosopher of science



Pierre M.M. DUHEM was born in Paris to Pierre-Joseph DUHEM, a commercial traveler. After schooling at the Collège Stanislas in Paris (1872), where he surprised his teachers by his great talent for mathematics, he studied science at the Ecole Normale Supérieure. In his Ph.D. thesis on thermodynamic potentials in chemistry and physics, following Josiah Willard GIBBS and Hermann VON HELMHOLTZ, he defined the criterion for the spontaneity of chemical reactions in terms of free energy rather than following the conception of maximum work, which had been stated 20 years before by P.E. Marcellin BERTHELOT. This disagreement with BERTHELOT, who was a leading authority of great influence, led to a long-lasting enmity and forced DUHEM to write his thesis on another subject. It also pushed his life into an increasing academic isolation. He rewrote his thesis on magnetism (1886) and taught at the universities of Lille (1887–1893), Rennes (1893–1894), and Bordeaux (1894–1916).

His fields of interest included thermodynamics, electromagnetism, hydrodynamics, and the history and philosophy of science. Today his contributions to shock wave physics are almost forgotten, although laid down in detail in his two books *Hydrodynamique, élasticité, acoustique* (1891) and *Recherches sur l'hydrodynamique* (1903–1904). However, they had an important influence on contemporary physicists and mathematicians, because they called attention to Pierre-Henri HUGONIOT's work on waves of finite longitudinal disturbances. The first book stimulated Jacques HADAMARD in his own work on wave propagation, a colleague at Bordeaux University for a period of 3 years who became his lifelong friend. One of his best-known disciples was Emile JOUGUET. DUHEM was also the first to show that true shock waves could only propagate in perfect fluids, which he called "true Hugoniot waves," while in real fluids only "quasi-shock waves" are possible, as he argued (1904).

His profound scientific output is enormous and comprises 45 books and nearly 400 papers. DUHEM, interested in many fields of physics of his time, was also a positivist like Ernst MACH, relying heavily on historical examples in presenting his philosophy of science. Controversies over scientific and political matters with P.E.M. BERTHELOT and others, however, resulted in a partial suppression and ignorance of his work. Today his numerous contributions, all of which were published in French, are being increasingly rediscovered and acknowledged. However, a detailed discussion of his contributions to shock wave physics from the modern point of view is still pending.

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PICTURE. DUHEM at age 50–54. Courtesy Académie des Sciences, Archives et Patrimoine Historique, Paris, France.

DUVALL, George Evered (1920–2003)

▪ U.S. physicist, dean of U.S. shock wave science

George E. DUVALL, son of George W. DUVALL, was born in Leesville, LA. After his junior year at Oregon State College (now Oregon State University), he left to work as an associate physicist on problems of underwater sound at the University of California Division of War Research in San Diego (1941–1945). He wrote or contributed to over 20 research reports on acoustics covering wave propagation, scattering, echo response from submerged objects, and piezoelectric transducers. After his return to Oregon State College, he completed his B.S. (1946) and then went to MIT, where he completed his Ph.D. in physics (1948). He worked on nuclear reactor problems at General Electric in Richland, WA (1948–1953), from 1950 heading the theoretical group there. In late 1953, he was hired by Dr. Thomas POULTER to work on shock wave problems at Stanford Research Institute (SRI) in Menlo Park, CA as a senior physicist (1954–1957). He became scientific director of SRI's Explosives and Extreme Pressure Laboratory (1957–1964), later named the Poulter Laboratory. Initially he concentrated his efforts on the thermodynamic and hydrodynamic aspects of shock wave propagation as needed for ballistic and metallurgical applications.

His work was primarily responsible for clarifying many fundamental theoretical issues related to shock wave propagation. DUVALL and his collaborators contributed to some of the earliest theoretical and experimental advances in the field, including such topics as hydrodynamic attenuation, material strength effects, optical techniques for free surface measurements, instabilities and multiple wave interactions, rate effects, studies on porous materials, impact welding, and detonation studies. Since 1964 he worked as a professor of physics at Washington State University (WSU), directing the university's Shock Dynamics Laboratory (SDL), now the Institute for Shock Physics (ISP). During this time he and his students made noteworthy contributions to the following problems: (1) shock-induced phase transitions and the incorporation of kinetic effects; (2) systematic calculations of the effects of transformation rates on the details of shock evolution; (3) nonlinear wave propagation in lattices; (4) understanding of atomic mechanisms controlling inelastic deformation in shocked crystals; (5) equations of state of solids and liquids; (6) electrical and thermoelectric measurements under shock loading; and (7) time-resolved spectroscopic studies to understand shock-induced chemical reactions.

He is author or coauthor of almost 170 articles or technical reports and supervised Ph.D. theses of over 25 students. He became the mentor for a whole generation of research scientists who themselves made significant contributions to shock wave physics and had distinguished careers at private and governmental laboratories. DUVALL was one of the founding members of the Association Internationale pour L'Avancement de la Recherche et de la Technologie aux Hautes Pression (AIRAPT). At international and national meetings he gave numerous lectures on the progress of shock wave physics in condensed matter and prepared worthwhile review articles, summarizing recent milestone achievements of this

rapidly growing discipline. Chairing the National Materials Advisory Board (NMAB), he was mainly responsible for the report on Shock Compression Chemistry in Materials Synthesis and Processing.

In 1989, he received the second Shock Compression Science Award of the American Physical Society (APS) "in recognition of his outstanding contributions to shock wave physics and his educational and organizational leadership in the shock physics community." In honor of DUVALL's great contributions to academic education, Washington State University offers the *George E. Duvall Scholarship*. This new scholarship recognizes outstanding achievements in graduate research in the area of shock compression science.

DUVALL died in Vancouver at the age of 82 after a long illness.

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EARNSHAW, Samuel (1805–1888)

▪ British clergyman and mathematician

Samuel EARNSHAW was born in Sheffield to Joseph EARNSHAW, a file-cutter who had been in Charity School as a boy. He began early to hold various teaching positions at Carver Street Schools in Sheffield (1819–1824). The Revd William H. BULL, curate of the Parish Church who had perceived young EARNSHAW's singular aptitude for mathematics, encouraged him to continue higher education. He entered St. John's College at Cambridge (1827), graduated as Senior Wrangler (1831), and was also first Smith's prizeman. He remained at Cambridge University as tutor and coach (1831–

1847), which brought him great renown, and became ordained deacon and priest. The Church Burgesses, recognizing his great learning, appointed him chaplain of Queen Mary's Foundation in the church and parish of Sheffield (1847–1888), which came with a considerable annual stipend. During his ministry he also took an active part in all religious, educational, and philanthropic movements and also published several books on mathematics and philosophy, including treatises on statics and dynamics, differential equations, and similar subjects, some of which went through several editions. He delivered many learned papers before the Sheffield Literary and Philosophical Society such as *On the Theory of Heat*, *What Geometry Says to Evolution*, and *The Arithmetic of Infinities*. He was the author of several books on mechanics, mathematics, and philosophy, some of which went through several editions.

In the 1840s, he got involved in fluid dynamics and related problems of solving partial differential equations. At first he investigated fluid motions such as solitary wave propagation and, in the 1850s, turning to acoustic waves, worked out a mathematical theory of sound. His interest in sounds of finite amplitude (*i.e.*, in shock waves) arose during his period at Sheffield. In the spring of 1851, he observed that a thunderstorm was terminated by a flash of lightning of great vividness, which was instantly followed by an awful crash. However, no damage was done at the locus of observation, but rather at a distance of more than a mile away. EARNSHAW, speculating on this phenomenon, concluded that violent sounds, for example emitted from a thunder clap, would propagate faster than gentle sound. In 1858, he first reported on this phenomenon at the Meeting of the British Association at Leeds and his attempt to treat this problem of sounds of finite amplitude on a mathematical basis. His interesting contributions certainly stimulated his contemporaries to turn to this unique branch of nonlinear acoustics.

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PICTURE. Courtesy Sheffield City Libraries, Sheffield, U.K.

EULER, Leonhard (1707–1783)

▪ Swiss theoretical and applied mathematician, physicist, and astronomer; cofounder of modern theoretical fluid dynamics

Leonhard EULER was born in Basel, Switzerland. He was the eldest son of Paul EULER, a Protestant minister, and brought up in Riehen, a small town near Basel. His father wanted to follow him into the church and sent him to the University of Basel to prepare for the ministry. He entered the university in 1720, first to obtain a general education before going on to more advanced studies. After receiving his master's degree in philosophy (1723), he turned to theology, thus fulfilling his father's wish. Johann BERNOULLI, a dear friend of his father, soon discovered EULER's great potential for mathematics, and during his years of study he attended lectures on mathematics given by J. BERNOULLI. In 1727, he

accepted an invitation by the newly organized St. Petersburg Academy of Sciences. He became professor of physics (1730) and professor of mathematics (1733). Besides his diverse activities in scientific and technical fields, he reorganized the university and the curriculum.

Owing to political problems in the Russian capital, he left Petersburg (1741) and accepted the invitation of the Prussian king FREDERICK II (the Great) to join the Berlin Society of Sciences (1741–1766). He was appointed director of the mathematical class of the Royal Prussian Academy (1744) and member of the board. The Prussian king charged him also with practical problems, such as supervision of the pumps and pipes of the hydraulic system at castle Sanssouci in Potsdam, the royal summer residence, or the translation of the book *New Principles of Gunnery* (1842) by the British ballistician Benjamin ROBINS. Here EULER added important enhancements and expanded ROBINS' work to a length many times that of the original text (1745). EULER's translation occupies an important place in the history of ballistics. It was retranslated into English by Hugh BROWN (1784) and Charles HUTTON (1805), both providing worthwhile additional notes. EULER's contribution to the evolution of theoretical fluid mechanics are significant. The momentum equation in the form we frequently use in modern compressible flow was derived by him (1748), as was the continuity equation in the general form (1757). Due to serious conflicts with king FREDERICK II over financial matters and his management of the Academy, EULER left Berlin (1766) and returned to St. Petersburg, where he continued working in leading positions until his death.

EULER's contributions to modern mathematics, encompassing also mathematical nomenclature, are enormous. For example, he defined a function as an analytic expression and introduced f for the mathematical term *function* – a word used by the Swiss mathematician Johann BERNOULLI in 1698 in an article on the solution to a problem involving curves – and included brackets for $f(x)$. In the 1750s, studying the motion of a vibrating string like some of his contemporaries, he found it useful to expand certain functions in terms of simpler ones, thus considering what we call today the "Fourier series solution of the wave equation." His work sparked a tremendous debate among the leading mathematicians of the day over the definition of the function concept, one of the greatest contributions of 19th-century mathematics. In the early 1750s, EULER worked out the equations for the motion of an inviscid compressible fluid: introducing the differential element of fluidic matter, he derived the differential forms of the mass (or continuity) equation and the momentum equation, the so-called "Euler equations." They were later extended by others by including the effect of viscosity (the Navier-Stokes equations).

In 1759, in a letter to Joseph L. DE LAGRANGE, EULER speculated on the possibility that the propagation of sound might depend on the "size of disturbances;" *i.e.*, on the intensity of sound – thus anticipating the shock wave problem.

During his lifetime EULER published about 560 books and articles, and many manuscripts were found unpublished among his personal belongings after his death. In September 1783 EULER died in St. Petersburg, where he is buried in the town's necropolis.

Astronomers named a crater on the near side of the Moon and a minor planet (asteroid 2002 EULER) after him.

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PICTURE. Engraving by Joseph-Friedrich-August DARBES. Courtesy Dibner Library of the History of Science and Technology, Smithsonian Institution Libraries. National Museum of American History, Washington, DC.
NOTE. EULER's original works are available online; *see The Euler Archive*; http://www.math.dartmouth.edu/~euler/.

FERRI, Antonio (1912–1975)

▪ Italian-born U.S. aeronautical engineer and inventor; pioneer of supersonic testing

Born in Norcia, Italy, Antonio FERRI studied electrical and aerospace engineering. After earning doctorates in industrial electrical engineering from the University of Rome (1934) and in aeronautical engineering from the Graduate School of Aeronautics at Rome (1936), he initially worked as an aerodynamic research scientist at the Italian Air Ministry's aeronautical research center in Guidonia (1935–1937), where he soon became head of the *Galleria Ultrasonora* (Supersonic Wind Tunnel) (1937–1940). In Guidonia he also studied various supersonic biconvex airfoil geometries, including a 10% thick biconvex airfoil at a Mach number of 2.13 – a concept that was later taken up in the U.S.A. in the design of the Bell X-2, a Mach 3 research rocket plane.

During World War II his supersonic wind tunnel was taken to Germany, where he temporarily continued his aerodynamic research (1940–1943). Returning to Italy, he joined the underground and became leader of the partisan brigade Spartaco against the Nazis (1943–1944). He was brought to the U.S.A. by the War Department, and he joined the National Advisory Committee for Aeronautics (NACA) and was assigned to the Langley Aeronautical Laboratory in Virginia. Initially working as a senior scientist (1944–1949) in wind tunnel testing of war planes, he became head of the gas dynamics branch (1949–1951).

Recruited by the Aerospace Department of the Polytechnic Institute of Brooklyn, FERRI was appointed professor of aerodynamics (1951–1964). During this period he installed at Freeport, Long Island the first American hypersonic wind tunnel, which, being from the blow-down type, allowed simulation of the high temperatures encountered in high-speed flow up to $M = 6$. Unlike with hypersonic shock tubes, the long operation time was particularly attractive to simulate the time-history of reentry phenomena of spacecraft and intercontinental missiles, which also helped to effectively design the nose cone to withstand the combined action of heat and aerodynamic loading during reentry. In 1964, FERRI joined the University of New York (NYU) as Astor professor of aerospace sciences (1964–1975). Later employed at NYU's Aerospace Energetics Laboratory in Westbury, NY on Long Island, he directed studies on sonic boom effects and air pollution problems originating from supersonic aircraft engines (1967–1975).

FERRI has been considered one of the most innovative experimentalists in aeronautics in the United States. He was always interested in propulsion and did pioneering work on supersonic inlets and supersonic compressors and also held numerous U.S. patents in these fields. He helped design a 2,300-mph (1,028 m/s) ramjet-powered fighter, the Republic XF-103, a high-speed, high-altitude aircraft specifically designed to intercept incoming enemy bombers. However, in 1957 the project was cancelled by the USAF in favor of the competing Convair F-102. His most recognized contributions were the "Ferri sled" (1957), a proposed spaceship design to better meet problems of reentry from outer space, and his "shroud technique" (1957), which allows one to channel the flow around large models in order to reproduce actual flight boundary layer and Reynolds number conditions. He was one of the leading pioneers of low-sonic-boom technology relevant to the design of supersonic-cruise aircraft.

Together with Nicholas J. HOFF and Paul A. LIBBY FERRI edited the Proceedings of the Conference on High-Speed Aeronautics, held in January 1955 at the Polytechnic Institute of Brooklyn. Together with Dietrich KÜCHEMANN and Laurence H.G. STERNE he also edited the 2-volume book *Progress in Aeronautical Sciences* (Pergamon Press, Oxford 1961/1962).

FERRI was cofounder and president of the General Applied Science Laboratories, Inc. (GASL) in Westbury, NY and a consultant to the aircraft industry. He received various scien-

tific awards from Italian, American, and British professional societies.

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FRIEDMANN [or Fridman; Russ. *ФРИДМАН*], Aleksandr Aleksandrovich (1888–1925)

▪ Russian mathematician, fluid dynamicist, and cosmologist; cofounder of Big Bang theory

Aleksandr A. FRIEDMANN was born in St. Petersburg (renamed Petrograd in 1920, renamed Leningrad in 1924). His father, Aleksandr FRIEDMANN, was a composer and ballet dancer and his mother a pianist. He graduated from the

gymnasium with the gold medal and entered the University of St. Petersburg (1906), where he became a student of Prof. Vladimir Andreevich STEKLOV, who founded the school of mathematical physics that later achieved considerable distinction. Together with the Russian mathematician Jakow D. TAMARKIN, FRIEDMANN wrote an unpublished paper on second-degree indeterminate equations that earned him a gold medal from the Department of Physics and Mathematics. After graduating from the university (1910) he was retained in the department to prepare for the teaching profession.

In 1913, he passed the examinations for the degree of master of pure and applied mathematics and was appointed to a position in the Aerological Observatory in Pavlovsk, a suburb of St. Petersburg, which involved him in meteorology. In the same year, he published a paper on meteorology, entitled (in translation) *On the Relationship of Temperature to Altitude*, in which he discusses the possible existence of an upper temperature inversion point in the stratosphere. During World War I, he served in an aviation detachment and later got involved in supervising the manufacture of measuring instruments in aviation. Thereafter, he became professor in the department of theoretical mechanics at Perm University (1918–1920) and worked as head, and later as director, of the Department of Theoretical Meteorology at the Geophysical Central Observatory of the Academy of Sciences in Petrograd (1920–1925). He studied a number of fundamental aerodynamic and hydrodynamic physical processes such as the motion of a compressible fluid under the influence of given forces with respect to some problems of treating cyclones and anticyclones, thereby creating "dynamical meteorology" – a new branch of atmospheric science.

In the early 1920s, he took up an interest in EINSTEIN's General Theory of Relativity (1916). FRIEDMANN's most prominent disciple was probably the Russian-born U.S. physicist George GAMOW, spiritual father of the Hot Big Bang Theory who studied, though only briefly, relativity under FRIEDMANN in 1925, the year of FRIEDMANN's death. FRIEDMANN published two classical papers in the prestigious German journal *Zeitschrift für Physik* on a dynamic model describing the evolution of the Universe in mathematical terms (1922, 1924). In his first paper, entitled (in translation) *On the Curvature of Space*, he found that even without the cosmological term there are still solutions of the field equations where matter has a finite density everywhere in space, provided this density is not time-independent. Supposing a closed Universe – so-called "Friedmann closed Universe" – his first solution showed that the radius of curvature of the Universe can be either increasing or a periodic function of time; *i.e.*, a Big Bang followed by expansion, then contraction and an eventual Big Crunch. Prior to FRIEDMANN, the German theoretical physicist Albert EINSTEIN had proposed a static, finite spherical Universe (1917). EINSTEIN, at first claiming that FRIEDMANN's solution does not satisfy the field equations, conceded after further study that FRIEDMANN was indeed right.

In July 1925, FRIEDMANN made a record-breaking ascent in a balloon to 7,400 m to make meteorological and medical observations. A few months later, shortly after falling ill on typhoid fever, he died at Leningrad at the early age of 37. He was awarded the George Cross (1915) for bravery in his flights during World War I and posthumously the Lenin Prize (1931) for his scientific work. Prof. Eduard A. TROPP and colleagues at Ioffe Technico-Physical Institute, summing up FRIEDMANN's contributions, appropriately wrote, "Just as COPERNICUS made the Earth orbit round the Sun, so FRIEDMANN made the Universe expand." Today, FRIEDMANN, together with the Belgian mathematician and astronomer Georges LEMAÎTRE, is considered the main founder of the Big Bang model.

The *Alexander Friedmann Seminars*, which have been held in St. Petersburg (1988, 1993, 1995, 1998), João Pessoa, Brazil (2002) and on Corsica, France (2004), became the international forum for astrophysicists to discuss actual topics of cosmology such as problems of gravitational theory, inflationary Universe, primordial radiation, dark matter, quantum effects in curved space-time, and observational cosmology. The first Friedmann Seminar held in 1988 (*see below*) was dedicated to the centenary anniversary of Alexander FRIEDMANN's birth. The *Alexander Friedmann Laboratory for Theoretical Physics* in St. Petersburg bears his name.

A crater on the far side of the Moon is named for him. The *Cosmonautics Day* is a Russian holiday celebrated every April 12 to commemorate GAGARIN's first manned space flight.

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http://www-history.mcs.st-andrews.ac.uk/history/Mathematicians/Friedmann.html.

PICTURE. From the MacTutor History of Mathematics Archive (*see above*).

FRIEDRICHS, Kurt Otto (1901–1982)

▪ German-born U.S. applied mathematician and theoretical fluid dynamicist

Kurt O. FRIEDRICHS was born in Kiel and attended elementary and high school in Düsseldorf, where he also began his university studies. After spending several years at different German universities, he completed his studies in Göttingen. There he wrote his Ph.D. thesis (1927) on the theory of elastic plates under Richard COURANT's supervision, then director of the Institute of Mathematics. FRIEDRICHS became his assistant and helped with the Courant-Hilbert book (1927). He went to the University of Aachen (1929) to join Theodore VON KÁRMÁN who had become the first professor of aeronautical engineering. In 1931, at 30 years of age, he was called to the TH Braunschweig as a full professor. In 1937, he emigrated to America and at New York University (NYU) joined Prof. COURANT, who already had emigrated by that time, in teaching and research.

Until the end of World War II his main contributions were in fluid dynamics and in elasticity with the U.S. applied mathematician James J. STOKER. Together with his colleague Joseph B. KELLER, an applied mathematician, he investigated in the 1950s the propagation, reflection, and refraction properties of weak shock waves. Conducting here groundbreaking work in pure and applied mathematics, he was author of several books. His main work was on partial differential equations in mathematical physics, using finite differences to prove the existence of solutions. In the shock physics community his name is well known as being the coauthor of COURANT's classical textbook *Supersonic Flow and Shock Waves.* He made many contributions to fluid dynamics; several of them, resulting from wartime work of the 1940s, were not published. These include work on fluid flow through nozzles, over surfaces of revolution, and in detonations and deflagrations.

Later FRIEDRICHS directed the Courant Institute (1966–1967) at NYU. He was a member of the National Academy of Sciences (from 1959) and recipient of the National Medal of Science (1977) "for bringing the powers of modern mathematics to bear on problems in physics, fluid dynamics and elasticity."

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http://www.friedrichs.us/x-history.html.

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GAGARIN [Russ. *ГАГАРИН*], Yuri Alekseyevich (1934–1968)

▪ Soviet cosmonaut; "First Man in Space" and first human to fly hypersonically

Yuri A. GAGARIN was born near Gzhatsk (now Gagarin) in the Smolensk region, west of Moscow. His father was a carpenter on a collective farm. After graduation as a molder from a trade school near Moscow (1951) he continued his studies at the industrial college at Saratov, where he took a course in flying. He entered the Soviet Air Force cadet school at Orenburg, where he graduated with top honors (1957). Selected with the first group of cosmonauts, he was eventually chosen for the historic orbital flight of 1961. His spacecraft Vostok 1 was launched at 9:07 A.M. Moscow time on April 12, 1961, orbited the Earth once in 1 h 29 min at a maximum speed of 28,968 km/h (about 8 km/s) and at a maximum altitude of 301 km, and landed safely at 10:55 A.M. in Siberia in the Sarov region. This famous flight during which GAGARIN experienced 8 g's during reentry was the first demonstration that problems of weightlessness and safe reentry into the Earth's atmosphere could be solved successfully, thus opening the door for all succeeding space flights. Hitting Mach 25 during reentry, he was the first human to fly at hypersonic velocity.

GAGARIN was awarded the Order of Lenin and given the titles of Hero of the Soviet Union and Pilot Cosmonaut of the Soviet Union. He was killed with another pilot in 1968 in the crash of a MiG-15 on a routine training flight near Moscow. The Cosmonaut Training Center, established in 1960 near Moscow, was renamed in 1968 the *Yuri Gagarin Cosmonaut Training Center* in memory of his famous space flight.

A crater on the far side of the Moon is also named for him.

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GAMOW, George Anthony [born Georgiy Antonovich] (1904–1968)

▪ Russian-born U.S. physicist and cosmologist; father of the Hot Big Bang theory

George A. GAMOW was born in Odessa, Russia, to Anton GAMOW, a teacher of Russian language and literature. He was educated at the University of Leningrad (now St. Petersburg), where he briefly studied relativistic cosmology under Alexander FRIEDMANN before turning to quantum theory. After receiving his Ph.D. (1928) from the University of Leningrad, he worked for brief periods at the universities of Göttingen, Cambridge, Copenhagen, Paris, and London. In 1933, he left Europe and emigrated to the U.S.A., where he held professorships at George Washington University (1934–1956) and the University of Colorado (1956–1968). During World War II, he served as a consultant to the Division of High Explosives in the Bureau of Ordnance of the U.S. Navy and studied the propagation of shock and detonation waves in various conventional high explosives. Later he cooperated with Edward TELLER and Stanislaw ULAM on the hydrogen bomb at Los Alamos. Together with TELLER he formulated the so-called "Gamow-Teller rules" for classifying subatomic particle behavior in radioactive decay, and attempted to apply the new understanding of atomic phenomena to astrophysics.

Being interested in astronomy since his childhood, he later turned to astrophysical problems and worked on the theory of the internal structure of red giant stars (1939). He was a major proponent of the Big Bang cosmological theory of the origin of the Universe, which was previously developed by the Russian mathematical physicist and fluid dynamicist Alexander FRIEDMANN (1922–1924) and, independently, by the Belgian cosmologist and priest Georges LEMAÎTRE (1927). GAMOW and collaborators suggested the so-called "Hot Big Bang model" (1946): they argued that at the beginning of the expansion of the Universe, matter was not only very dense but also very hot: as a result, thermonuclear reactions would have taken place that promoted the formation of all elements heavier than hydrogen, especially of helium. In 1948, they proposed that low-temperature radiation has survived as a vestige of the Big Bang and that by the present time it would have been diluted to a temperature of only about 10 K. This was confirmed in 1965 by Arno A. PENZIAS and Robert W. WILSON, two U.S. physicists at Bell Telephone Laboratories, who discovered cosmic microwaves at a wavelength of 7 cm. This radiation, which exceeded the radiation coming from known sources by a factor of about 100, corresponds to an approx. 3-K black-body radiation – thus strongly supporting the Lemaître Big Bang model of an expanding Universe. GAMOW also worked out a theory for the origin of the elements in the Big Bang, his Alpha-Beta-Gamma Theory (1948), and speculated on the question of whether physical constants change over time.

In his later life, GAMOW became interested in biology and genetics and correctly assumed that the DNA structure forms a code that directs protein synthesis. He wrote almost 140 scientific articles and 28 books, mostly for nonscientists, which earned him the UNESCO Kalinga Prize (1956). In 1994, the 90th anniversary of his birth, the International Conference *Astrophysics and Cosmology after Gamow* was held in Odessa and St. Petersburg to discuss actual problems in astrophysics and cosmology, followed 5 years later by the *Gamow Memorial International Conference* (GMIC-99). The *George Gamow Lecture* is a prominent lecture series given at the University of Colorado at Boulder that brings renowned scientists to campus to address a general audience of nonscientists. At George Washington University (Washington, DC), the *George Gamow Undergraduate Research Fellowship* is designed to give promising undergraduates the opportunity to engage in a well-defined research project under the guidance of a faculty member in the chosen field of study.

A crater on the far side of the Moon is named for him.

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GLASS, Irvine Israel (1918–1994)

▪ Polish-born Canadian aeronautical engineer and aerospace scientist

Irvine I. GLASS was born at Slupia Nowa (near Kielce, Poland) and emigrated with his parents to Canada at the age of 12. At the University of Toronto he studied aeronautical engineering, where he received his B.Sc. in engineering physics (1947) and his M.Sc. in aeronautical engineering (1948). As a Ph.D. candidate he entered the newly founded University of Toronto Institute of Aerophysics (UTIA), later renamed the University of Toronto Institute for Aerospace Studies (UTIAS). After obtaining his Ph.D. (1950) in aerophysics, he established and headed the Gas Dynamics and Shock-Wave Phenomena Group until his retirement (1983), and thereafter worked as professor emeritus.

Together with his numerous students and research associates, many also from abroad, he contributed within a period of more than 40 years to a wide field in shock wave physics: (1) Theoretical and experimental study of shock tubes; (2) fundamentals of shock wave and rarefaction wave dynamics; (3) nonstationary oblique shock wave interactions in perfect, imperfect, and dusty gases with various boundaries and establishment of gasdynamic criteria for transition between various reflection configurations; (4) high-temperature nonequilibrium supersonic plasma flow phenomena behind strong shock waves; (5) shock-induced chemical kinetics; (6) development of hypersonic launchers; (7) study and simulation of sonic boom phenomena and their effects on humans and animals; (8) synthesis of new materials using shock implosion techniques; and (9) shock effects in dusty gases. He wrote the popular book *Shock Waves and Man* (1974), which interprets the rapidly growing field of shock wave research to a wide public. His textbook *Nonstationary Flows and Shock Waves* (1994), written together with Jean P. SISLIAN, covers the use of shock tubes to investigate physical and chemical-reactive effects in supersonic and hypersonic flows.

Prof. GLASS is author or coauthor of more than 200 papers and became a leading authority on shock waves. He served at the University of Toronto for more than 45 years and was named a Distinguished University Professor (1981), the highest honor that the university can bestow on one of its faculty members. He was also a visiting professor at Imperial College, London (1957–1958), Kyoto University (1975), and Haifa's Institute of Technology and awarded an honorary professorship from the Chinese Aeronautical Institute at Nanjing

(1985). He was a cofounder of the journal *Shock Waves* (Springer, Berlin Heidelberg New York) and its first editor-in-chief (1990–1994). In the first issue of this journal (1991), he reviewed the research activities and problems tackled by him and his team at UTIAS over the preceding four decades.

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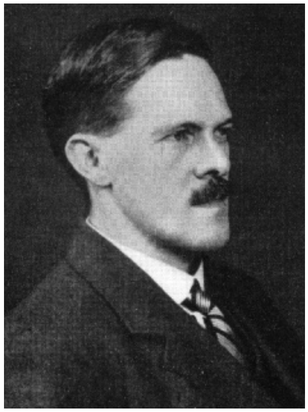
GLAUERT, Hermann (1892–1934)

▪ British aeronautical engineer



Hermann GLAUERT was born in Sheffield to Louis GLAUERT, a naturalized British citizen of German birth who settled in England as a young man. Hermann GLAUERT was educated at the local King Edward VII School and at Trinity College in Cambridge, where he gained the Tyson Medal for astronomy (1913), the Isaac Newton Studentship in astronomy and physical optics (1914), and the Rayleigh Prize for mathematics (1915). At the outbreak of World War I he studied astronomy at Cambridge but later turned to aeronautics, accepting an appointment on the staff of the Royal Aircraft Establishment (RAE) at Farnborough (1916–1934). GLAUERT entered the aerodynamics research division and later became Principal Scientific Officer and head of the aerodynamic department. His initial studies related to the analysis of experimental work resulting from the engineering design of aeroplanes and were laid down in numerous reports and memoranda published by the Aeronautical Research Committee (1917–1920). This stimulated him to further develop existing aerodynamic theories by Frederick LANCESTER, Wilhelm KUTTA, and Ludwig PRANDTL and to apply them to all problems of flight, particularly with a view to its use by engineers. His book *The Elements of Aerofoil and Airscrew Theory* (1926), which quickly disseminated PRANDTL's airfoil and wing theory around the English-speaking world, became the standard reference source on incompressible flow and was later also translated into German

(1929). He was one of the first in England who contributed to the theory of flight at high speed and the effect of compressibility on the lift force of an airfoil (1928), thereby, independently of PRANDTL in Göttingen, working out a rule for subsonic airflow that describes the compressibility effects of air at high speeds, the so-called "Prandtl-Glauert rule."

GLAUERT was killed by a falling tree in an explosion accident at Farnborough while walking in Fleet Common Park with his children and watching the demolition of a tree from a position that he was told was safe.

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GOLDBERG, Viktor (1903–1978)

▪ Latvian urologist

Viktor GOLDBERG was born in Riga, then capital of the Russian province of Latvia. After attending the gymnasium in Riga he began to study medicine at the University of Würzburg, Germany, and took his M.D. at the University of Vienna (1927). His first appointment was a position as an assistant physician at the Department of Surgery of the Bikur-Chalim Hospital in Riga (1927–1929). Thereafter he went to Berlin where he worked at the department of urology of the St. Hedwig Hospital under the guidance of the German surgeon Alexander VON LICHTENBERG, who introduced intravenous urography (pyelography) in order to diagnose nephritic disorder.

GOLDBERG studied the connection between the specific density of urine and the physiological processes in the kidney, and, together with Isidor TRAUBE and Konstantin SKUMBURDIS from the Technische Hochschule Berlin-Charlottenburg, he investigated the colloid-chemical generation of kidney stones. After suffering a period of racial persecution because of his Jewish ancestry, GOLDBERG resumed his research only at the end of World War II. In Riga he became head physician at the First Municipal Clinical Hospital, directing also the department of urology of the Medical Institute Riga. He also invented a new radiographic method for diagnosing the lower urethra system by incorporating a contrast liquid (genitography, 1946) and constructed a new apparatus for removing calculi debris after shock wave treatment, which he called the "hydrodynamic evacuator" (litholapaxie, 1977). His greatest contribution to medicine, however, was the first demonstration of transurethral shock lithotripsy and also its further clinical development for routine use. During his retirement he moved to Stuttgart (1973–1978), where he worked at Prof. Hans J. REUTER's hospital until his death.

ORIGINAL WORKS. With I. TRAUBE and K. SKUMBURDIS: *Beiträge zum Problem der Nierensteinbildung.* Münchener Medizinische Wochenschrift **79**, 1083-1085 (1932) — *Studium über Konkrementbildung und Verhinderung der Steinentstehung in den Harnwegen.* Z. Urolog. Chir. **35**, 347-358 (1932) — *Zur Geschichte der elektrohydraulischen Lithotripsie (EHL).* In: (E. SCHMIEDT, ed.) *Symp. Biophysikalische Verfahren zur Diagnose und Therapie von Steinleiden der Harnwege*. BMFT Symp., Meersburg, Germany (1976). Wissenschaftliche Berichte, Dornier System GmbH, Friedrichshafen, Germany, pp. 130-131.

SECONDARY LITERATURE. (S. TAYLOR, ed.) *Who's who in central and east Europe.* Central European Times, Zurich (2nd edn., 1937) — M. KLAUS-GOLDBERG: *Zur Geschichte der elektrohydraulischen Lithotripsie: V. GOLDBERG: Eine neue Methode der Harnsteinzertrümmerung, elektrohydraulische Lithotripsie.* Der Urologe **19B**, 23-27 (1979) — A. HUTTMANN: *Von der transurethanen elektrohydraulischen Lithotripsie zur extrakorporalen Stoßwellenzertrümmerung von Harnsteinen.* Ibid **28B**, 220-225 (1988) — *Viktor GOLDBERGs literuras saraksts.* This list of GOLDBERG's publications was compiled by the Medicīnas Zinātniskā Bibliotēka, Riga, Latvia (1999) — M.A. REUTER (with R.M. ENGEL and H.J. REUTER): *History of endoscopy.* Kohlhammer, Stuttgart (1999), p. 481 — R.M. ENGEL: *De historia lithotomiae* [includes electrohydraulic and laser lithotripsy]. Curator of the William P. Didusch Museum of the American Urology Association, Baltimore, MD; http://www.urolog.nl/urolog/php/content.php?doc=lithotomia&profmenu=yes.

PICTURE. Courtesy Mrs. G. TIFONOWA, Medicīnas Zinātniskā Bibliotēka, Riga, Republic of Latvia.

HADAMARD, Jacques Salomon (1865–1963)

▪ French mathematician and theoretical fluid dynamicist

Jacques S. HADAMARD was born in Versailles. His father Amadée HADAMARD was a professor of Latin and his mother taught piano. After studying at the Ecole Normale Supérieure (1884–1888), he taught at the Lycée Buffon in Paris (1890–1893), where he also received his Ph.D. in sciences (1892). He began as a lecturer at the University of Bordeaux (1893–1897) and the Sorbonne (1897–1909). Returning to Paris, he became entrance examiner (1910–1911) and then professor (1912–1937) at the Ecole Polytechnique and the Ecole Centrale des Arts et Manufactures (1920–1937). He also taught at the Collège de France (1907–1937), where he succeeded Prof. Camille JORDAN as chair of analysis (1912). Here he established a seminar (1913) that soon became a favorite meeting place for leading mathematicians.

In mathematics, HADAMARD contributed to (1) the analytic continuation of a Taylor series and the distributions of the singularities of the series in terms of the nature of its coefficients; (2) the theory of functions of a complex variable; (3) the famous problem concerning the distribution of the prime numbers; (4) differential geometry; (5) the solution to his maximum determinant problem, the so-called "Hadamard matrix" of order *n* which can be used to make error-correcting codes; and (6) the problem of solving equations with partial derivatives. He also addressed various problems of hydrodynamics, mechanics, and probability theory of his time. In his book *Leçon sur la propagation des ondes et les équations de l'hydrodynamique* (1903), he treats waves of finite amplitude in a general manner using his "method of operator differences." This book, a result of his teaching activities in the period 1898−1900 and fallen almost into oblivion, is now increasingly being cited by present shock physicists as an important early source of the theoretical treatment of shocks. The starting point of getting involved in shock waves was Pierre-Henri HUGONIOT's work on the rectilinear movement of a gas, or rather Pierre DUHEM's exposition of it in his lectures and in conversations that took place in the years 1893 to 1897. He termed shock discontinuities *ondes d'accélération* ("acceleration waves") to underline the steepening process, but he also used the designation *onde de choc* ("shock wave") to illustrate the wave nature of the propagating discontinuity. HADAMARD theoretically investigated vorticity effects in shock waves and discovered that curved shock waves produce vorticity, while a vortex-free flow, passing through a plane shock wave, remains vortex-free – the so-called "Hadamard theorem."

HADAMARD also first investigated analytically the formation of shock waves in elastic solids. In 1923, in a series of lectures given at Yale University, he formulated in mathematical terms three different meanings of the "Huygens principle" he found in the literature of his time. The so-called "Hadamard problem" consists in classifying all second-order hyperbolic operators that obey the Huygens principle, up to trivial relations (1932). A *Hadamard material* is one in which longitudinal waves may propagate in every direction when the material is homogeneously deformed.

HADAMARD wrote about 300 scientific papers and several books for a wider audience. He was an associate member of several foreign academies and held honorary doctorates from many foreign universities.

ORIGINAL WORKS. *Leçon sur la propagation des ondes et les équations de l'hydrodynamique.* A. Hermann, Paris (1903); Chelsea, New York (1949) — *Remarque au sujet de la note de M. Gyözö ZEMPLEN.* C. R. Acad. Sci. Paris **141**, 713 (1905) — *Recherches sur les solutions fondamentales et l'intégration des équations linéaires aux dérivées partielles (2e Mém.).* Ann. Ecole Norm. Sup. **22**, 101-141 (1905) — *Sur les ondes liquides.* C. R. Acad. Sci. Paris **150**, 609-611, 772-774 (1910) — *Cours d'analyse professé à l'Ecole Polytechnique.* A. Hermann, Paris (1927) — *Lectures on CAUCHY's problem in linear partial differential equations* [Silliman Lecture]. Yale University Press, New Haven, CT (1928) — *Le problème de CAUCHY et les équations aux dérivées partielles linéaires hyperboliques.* A. Hermann, Paris (1932) — *An essay on the psychology of invention in the mathematical field.* Princeton University Press, Princeton, NJ (1949) — *La théorie des équations aux dérivées partielles.* Gauthier-Villars, Paris (1964) — *Œuvres de Jacques HADAMARD.* 4 vols., Editions du CNRS, Paris (1968).

SECONDARY LITERATURE. C. TRUESDELL and R. TOUPIN: *The classical field theories.* In: (S. FLUEGGE, ed.) *Handbuch der Physik.* Springer, Berlin (1960), vol. III/1 — A.S. PREDVODITELEV: *HADAMARD's method of operator differences, and applications.* In: (A.S. PREDVODITELEV, ed.) *Gas dynamics and physics of combustion.* Israel Program for Scientific Translations, Jerusalem (1962), pp. 3-39 — H. HEILBROWN and L. HOWARTH: *Jacques HADAMARD.* Nature **200**, 937-938 (1963) — M.L. CARTWRIGHT: *J. HADAMARD.* J. Lond. Math. Soc. **40** [I], 722-748 (1965); Biogr. Mem. Fell. Roy. Soc. (Lond.) **11**, 75-99 (1965) — P. LEVY, S. MANDELBROJT, B. MALGRANGE, and P. MALLIAVIN: *La vie et l'œuvre de Jacques HADAMARD.* L'Enseignement Mathématique, No. 16. Université de Genève (1967) — P. CURRIE and M. HAYES: *Longitudinal and transverse waves in finite elastic strain. Hadamard and Green materials.* IMA Appl. Math. **5**, No. 2, 140-161 (1969) — P. CURRIE: *A note on shock waves in elastic Hadamard and Green materials.* ZAMP **22**, 355-359 (March 1971) — S. MANDELBROJT: *J. HADAMARD.* In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography.* Scribner, New York, vol. 6 (1972), pp. 3-5 — A.J. WILLSON: *Surface waves in restricted*

Hadamard materials. Pure Appl. Geophys. **110**, No. 1, 1967-1976 (Dec. 1973) — V. MAZ'YA and T. SHAPOSHNIKOVA: *Jacques HADAMARD, a universal mathematician.* Am. Math. Soc. & Lond. Math. Soc., Providence, RI (1990).
PICTURE. In the public domain, taken from Wikipedia, the free encyclopedia; http://fr.wikipedia.org/wiki/Image:Hadamard.jpg.

HAEUSSERMANN, Carl (1853–1918)

▪ German chemist

The son of a Protestant minister, Carl HAEUSSERMANN was born in Stuttgart. After attending the gymnasium, he finished an apprenticeship in a local pharmacy, whereupon he decided to study chemistry at the Polytechnikum Stuttgart (1869) and the TH Munich (1871–1873), where he became private assistant of Prof. Emil ERLENMEYER, an experimental chemist. Working in the first instance as a chemist in the chemical industry and being involved in the fabrication of nitrobenzene and aniline dyes and in oil refinery, he took his Ph.D. at the University of Heidelberg (1876) and shortly afterwards habilitated in Stuttgart (1877) on the fabrication of aniline dyes. He also worked temporarily in the French dye industry at Paris (1878–1880) and several years as a consultant to the Chemische Fabrik Griesheim-Elektron, which offered him a leading position. He became assistant director and later member of the board, supervising the fabrication of aniline dyes and derivatives (1885–1891). In addition, with the permission of the Prussian War Ministry he acted as consulting chemist to the Royal Powder Mills in Hanau. This activity brought him into close contact with actual problems of nitroexplosives, particularly with their manufacturing techniques and explosive properties.

During his stay at Chemische Fabrik Griesheim-Electron he became aware of trinitrotoluol or TNT (hexanitrodiphenylamine) and began to work out a method of manufacturing that became the standard method for many years. In 1891, he first discovered the explosive properties of trinitrotoluol. TNT is very stable, rather insensitive to shock, almost insoluble in water, neutral, and does not attack metals. The commercial production of TNT began in Griesheim around 1893, but production on a large scale did not start until the early 20th century. He first suggested the military use of TNT and recommended it as a filling for shells, a practice that was followed as early as 1901. Because of these outstanding features it became by far the most important explosive for blasting charges of all kinds of weapons in both world wars.

HAEUSSERMANN held the Chair of Chemical Technology at the Technische Hochschule Stuttgart (1891–1906). He died of a heart attack on a business trip to the moorlands of Günzburg/Ulm, which he intended to inspect as a possible new fuel resource. His pioneering contributions to the chemistry of nitro explosives, nitrocelluloses, and combustibles made him internationally renowned.

ORIGINAL WORKS. *Über die explosiven Eigenschaften des Trinitrotoluols.* Z. Angew. Chem. **4**, 508-511 (1891) — *Verfahren zur Herstellung von Trinitrotoluol.* Ibid. **4**, 661-662 (1891) — *Les matières explosives en 1892.* Moniteur Sci. **7**, 861-863 (1893) — *Sprengstoffe und Zündwaren.* Metzler, Stuttgart (1894) — *Brenn- und Explosivstoffe* [Jahresfachreferat]. In: (R. MEYER, ed.) Jb. Chemie. Vieweg, Braunschweig (1897–1914), vol. VII-XXIV — *Wesen und Wirkungsweise der modernen Explosivstoffe.* Verein vaterländ. Naturkunde (Württ.) **59**, 328-335 (1903) — *Zur Kenntnis der Nitrocellulose.* Ber. Dt. Chem. Gesell. **36**, 3956 (1903), Ibid. **37**, 1624-1625 (1904) — *Alfred NOBEL und die Erfindung der Nitroglyzerinpulver.* Union Dt. Verlagsgesell., Stuttgart (1904) — *Über die Denitrierung der Pyroxyline.* Chemiker-Z. **29**, 420-422 (1905) — *Zur Kenntnis der Pyroyline.* Z. ges. Schieß- u. Sprengstoffwesen **1**, 305 (1906) — *Zur Kenntnis der Xyloidine.* Ibid. **1**, 39 (1906); Ibid. **2**, 426 (1907); Ibid. **3**, 305-306 (1908) — *Über die Einwirkung der Salpetersäure auf Cellulose.* Ibid. **3**, 123-124 (1908) — *Gedächtnisrede auf Christian Friedrich SCHÖNBEIN.* Z. ges. Schieß- u. Sprengstoffwesen **4**, 433-434 (1909) — *Über das Verhalten der Zellulose gegen reine Salpetersäure.* Z. Angew. Chem. **23**, 1761-1763 (1910); Ibid. **26**, 456 (1913) — *Über die explosiven Eigenschaften des Trinitrotoluols.* Z. ges. Schieß- u. Sprengstoffwesen **8**, 378-379 (1913) — *Die Nitrozellulosen, ihre Bildungsweisen, Eigenschaften und Zusammensetzung.* Vieweg, Braunschweig (1914).
SECONDARY LITERATURE. (Ed.) *Carl HAEUSSERMANN †.* Z. ges. Schieß- u. Sprengstoffwesen **13**, 325-327 (1918) — C. HELL: *Carl HAEUSSERMANN †.* Z. Angew. Chem. **31**, 413-414 (1918) — A. SCHWEITZER: *Carl HAEUSSERMANN †.* Chemiker-Z. **42**, 397-398 (1918) — B. LEPSIUS: *Carl HAEUSSERMANN.* Ber. Dt. Chem. Gesell. **51**, 1683-1685 (1918).
PICTURE. Photo Deutsches Museum, Munich, Germany.

HERMANN, Rudolph (1904–1991)

▪ German-born U.S. physicist and aerospace engineer

Rudolph HERMANN was born in Leipzig, where he studied physics, mathematics, and astronomy at the university and

also received his Ph.D. (1929). After serving there as an assistant in the Department of Applied Mechanics and Thermodynamics (1929–1933), he accepted a research fellowship offered by the TH Aachen (1933–1934), where he became assistant at Prof. Carl WIESELSBERGER's Institute of Aerodynamics. Heading there the Supersonic Wind Tunnel Division (1934–1937), he began much pioneering work at the 10×10 cm^2 supersonic wind tunnel ($M = 3.3$), performing for the Heereswaffenamt (Army Ordnance Office) first aerodynamic tests of the A-3rocket, a fore-runner of the A-4 (later known as the "V2"). In addition, he habilitated (1935) and lectured in supersonic aerodynamics (1936–1937). Selected by the German rocket pioneer Werner VON BRAUN to install the new supersonic aerodynamic institute at the Heeresversuchsanstalt (HVA) Peenemünde-Ost, the Rocket Research & Test Facility of the German Army, he became its first and only director (1937–1945). Compared to the Aachen facility, his team began to install a more advanced, 40×40 cm^2 wind tunnel that, depending on the selected nozzle geometry, later allowed one to choose different Mach numbers ranging from 1 to 4.4. His major research activities were devoted to the model studies of the A-4 and A-5 rockets in the supersonic wind tunnel, particularly to (1) the investigation of the dependency of the trajectory on the inclination angle of the launching track and the acceleration due to thrust; (2) three-component measurements of aerodynamic forces; (3) the determination of the aerodynamic characteristics of missiles and location of the center of pressure; and (4) calculations of the skin and warhead temperature. After evacuation of the test facility to the small town of Kochel in the Bavarian Alps (1943), HERMANN also directed, until the end of war, the Wasserbauversuchsanstalt or WVA (Hydraulic Engineering Testing Facility) – a code name for the secret aerodynamic institute. He supervised plans to install a more advanced, huge hypersonic wind tunnel (1×1 m^2, $M = 10$), which, however, never opened because of Germany's defeat.

After the war HERMANN served as consultant for hypersonic wind tunnels and ramjet engines to the Wright-Patterson Air Force Base in Dayton, OH (1945–1950). He was professor of aeronautical engineering at the University of Minnesota, heading there also the hypersonic facilities at Rosemount Aeronautical Laboratories (1950–1962). He eventually transferred to the University of Alabama in Huntsville and was appointed professor of physics and aerospace engineering at the University of Alabama, directing also its research institute. HERMANN contributed to various fields of fluid dynamics, such as pipe friction, free convection heat transfer, viscosity of non-Newtonian fluids, fin-stabilized projectiles, guided missiles, supersonic and hypersonic wind tunnels and diffusers, film cooling, hypersonic physics, and reentry of satellite vehicles.

After his retirement (1969) he gave guest lectures at various international research institutions and dedicated himself to the history of science and technology. He published one book and over 100 scientific papers.

ORIGINAL WORKS. *Experimentelle Untersuchungen zum Widerstandsgesetz des Kreisrohres bei hohen Reynolds'schen Zahlen und großen Anlauflängen.* Dissertation, Universität Leipzig (1929); Akad. Verlagsgesell. Leipzig (1930) — With T. BURBACH: *Strömungswiderstand und Wärmeübergang in Rohren.* Akad. Verlagsgesell., Leipzig (1930) — *Turbulenzentstehung bei Wärmeübergang durch freie Konvektion an senkrechter Platte und waagerechtem Zylinder.* ZAMM **13**, 433-434 (1933) — *Wärmeübergang bei freier Konvektion am waagerechten Zylinder in zwei-atomigen Gasen.* Habilitationsschrift, T.H. Aachen (1935); VDI-Forschungsheft Nr. 379 (July/Aug. 1936) — *Der Kondensationsstoß in Überschall-Windkanaldüsen.* Luftfahrtforsch. **19**, 201-209 (1942) — *Entwicklung flügelstabilisierter Geschosse zum Zwecke der Leistungssteigerung.* Schriften Dt. Akad. Luftfahrtforsch. Nr. 1059/43 [gKdos, geheime Kommandosache], 9-31 (1943/1944) — *The supersonic wind tunnel of the Heereswaffenamt and its application in external ballistics.* Interner Forschungsbericht, Kochel, Bavaria (June 16, 1945). Microfilm Mi 56-4553 [*see* Natl. Union Cat., Library of Congress, Washington, DC (1972), vol. 242, p. 259] — *Theoretical calculations of the diffuser efficiency of supersonic wind tunnels with free jet test section.* Heat Transfer and Fluid Mechanics Institute, Berkeley, CA (1949). ASME, New York (May 1949), pp. 255-270 — *Diffuser efficiency and flow process of supersonic wind tunnels with free jet test section.* Air Force Tech. Rept. No. 6334, Wright Field, OH (Dec. 1950) — *Diffuser efficiency of free-jet supersonic wind tunnels at variable test chamber pressure.* J. Aeronaut. Sci. **19**, 375-384 (1952) — *Supersonic diffuser problems for inlet ducts and wind tunnels in one-dimensional analysis.* Proc. 2nd Midwestern Conf. Fluid Mechanics [Ohio State Univerity, Columbus, OH, March 1952]. In: (A. TIFFORD, ed.) *Ohio State University studies. Engineering series.* College of Engineering, Ohio State University, Columbus, OH (1952), vol. 21, No. 3, pp. 231-242 — *Supersonic inlet diffusers and introduction to internal aerodynamics.* Minneapolis-Honeywell, MN (1958) — *Supersonic inlet diffusers and introduction to internal aerodynamics.* Minneapolis-Honeywell Regulator, Minneapolis, MN (1958) — *The supersonic wind tunnel installations at Peenemünde and Kochel, and their contributions to the aerodynamics of rocket-powered vehicles.* Selected papers from the 32nd Int. Astronautical Congr. [Rome, Sept. 1981]. In: (L.G. NAPOLITANO, ed.) *Space: mankind's fourth environment*. Pergamon Press, Oxford (1982), pp. 435-446.

SECONDARY LITERATURE. W. KRAUS: *Der Überschall-Windkanal von Peenemünde.* Interavia **6**, 558-561 (1951) — H. KURZWEG: *The aerodynamic development of the V2.* AGARD First Guided Missiles Seminar [Munich, April 1956]. In: (T. BENECKE and A.W. QUICK, eds.) *History of German guided missile development.* Appelhaus, Brunswick (1957), pp. 50-69 —

H.O. RUPPE: *Rudolf HERMANN 65 Jahre.* Z. Flugwiss. **17**, 459 (1969) — (Ed.) *Zum 70. Geburtstag von R. HERMANN.* Ibid. **22**, 436 (1974) — P.P. WEGENER: *The Peenemünde wind tunnels.* Yale University Press, New Haven, CT (1996).

PICTURE. Photo Deutsches Museum, Munich, Germany.

NOTE. Shortly after World War II, the original technical reports of the Aerodynamic Institute, covering both the periods at Peenemünde and at the WVA in Kochel, were transferred to the U.S. Army and compiled by its Ordnance Dept. as "German Documents (GD);" *see* WEGENER's book cited above, pp. 90-96.

HERTZ, Heinrich Rudolf (1857–1894)

▪ German physicist; pioneer of theoretical collision mechanics

Heinrich R. HERTZ was born in Hamburg into a prosperous and cultured family. His father, Gustav HERTZ, was a barrister and later a senator. Educated in modern and ancient languages, he passed his Abitur at the Johanneum Gymnasium (1875) in Hamburg. He prepared for an engineering career in Frankfurt, Dresden, and Munich, but finally decided to attend a university instead of a polytechnic school. After spending a year in Munich, he continued his studies in Berlin (1878), in addition to establishing close contact with Hermann VON HELMHOLTZ and Gustav KIRCHHOFF and winning a prize awarded by the Berlin Philosophical Faculty on an experimental problem of electrical inertia (1879). He wrote his Ph.D. thesis on electromagnetic induction (1880) and worked as an assistant to VON HELMHOLTZ at the Berlin Physical Institute.

At this time he became interested in the theory of compression of elastic bodies, and in January 1881 he presented his famous paper on the classical problem of collision (publ. 1882). HERTZ not only offered the general solution of the problem, but also applied it to particular cases and even prepared a numerical table to facilitate practical applications. Extending his theory to the impact of two spheres, he derived formulas for calculating the stress and duration of impact. Subsequently he studied the hardness of materials, which is the crucial point in treating the complicated phenomenon of impact.

Followed by a short period as a lecturer at the University of Kiel (1883), he became professor of physics at the Technische Hochschule Karlsruhe (1885–1889), where he performed his famous experiments of broadcasting and receiving radio waves and measuring their length and velocity. Accepting an offer from the Prussian Ministry of Culture, he moved in 1888 to Bonn University and became professor of physics and director of the Physics Institute as successor to Rudolf CLAUSIUS. But during the almost 5 years that he spent in Bonn, HERTZ abandoned almost all experimental work and devoted 3 years to difficult theoretical work on mechanics, which culminated in the posthumous publication in 1894 of his book *Die Prinzipien der Mechanik in neuem Zusammenhange dargestellt* (The Principles of Mechanics Presented in a New Form, London 1899). On January 1, 1894 he died of blood poisoning at the early age of 36.

His name was given to the unit of frequency (hertz, abbreviated Hz), which replaced the use of cycles per second for the unit of frequency in the late 1960s, and electromagnetic waves in the radio and radar spectrum (*Hertzian waves*) are named in honor of him. In mechanics, the *Hertzian crack* is a localized cone-shaped crack (*Hertzian cone*) that appears at the point of contact or low-velocity impact, and in the *Hertzian fracture* test the fracture of a brittle solid is studied under a spherical indenter.

A crater on the far side of the Moon is named for him.

ORIGINAL WORKS. *Über die Berührung fester elastischer Körper.* J. Reine u. Angew. Math. **92**, 156-171 (1882) — *Über die Berührung fester elastischer Körper und über die Härte.* Verhandl. des Vereins zur Beförderung des Gewerbefleißes (Berlin) **61**, 449-463 (Nov. 1882) — *Gesammelte Werke.* A. Barth, Leipzig; Bd. III (1894): *Die Prinzipien der Mechanik in neuem Zusammenhang dargestellt. See* chap. *Von den Unstetigkeiten der Bewegung*, pp. 286-306 — *The principles of mechanics: presented in a new form.* Dover Publ., New York (1956).

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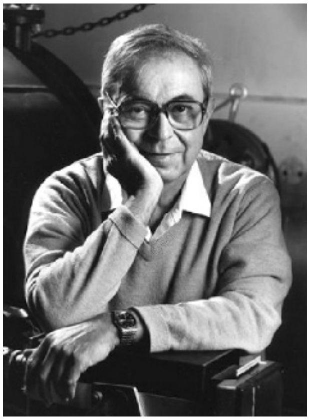
PICTURE. Archiv der Rheinischen Friedrich-Wilhelms-Universität Bonn, Germany.

HERTZBERG, Abraham ("Abe") (1922–2003)

▪ U.S. aerospace engineer, gas dynamicist and inventor; the "Idea Man"



Abraham HERTZBERG was born in the Bronx, NY. Shortly thereafter his family moved to Richmond, VA. He graduated from Virginia Polytechnic Institute with a Bachelor's degree in 1943 and started working at Curtiss-Wright Corporation that same year as an aerodynamicist. Near the end of World War II, he became a flight test engineer for the Army Air Force. Following his discharge from the military in 1946, he returned to school as a student of Prof. Arthur KANTROWITZ at Cornell University, Ithaca, NY, and received the M.S degree in 1949, writing a dissertation on hypersonic theory. Between 1950 and 1954 he took additional graduate-level courses in physics, chemistry, and gas dynamics at the University of Buffalo, NY, but because of his intense commitment to his work (*q.v.*) never pursued a Ph.D.

In 1949, HERTZBERG joined the Cornell Aeronautical Laboratory (CAL), Buffalo, NY. He was promoted to Assistant Head (1957) and Head of the Aerodynamics Research Department (1959–1965). During his sixteen years at CAL, HERTZBERG and his group made basic contributions in the fields of supersonic and hypersonic aerodynamics and hypersonic test facilities. In the 1950s, HERTZBERG proposed and developed a shock tunnel facility, which became accepted throughout the world as a standard hypersonic research tool. He was also responsible for the wave superheater, used for studies of ablative phenomena. Aerodynamic contributions included basic studies of viscous effects at hypersonic speeds and nonequilibrium flow phenomena. In the early 1960s, HERTZBERG carried out pioneering work in the development of gasdynamic lasers and laser-induced fusion systems. In addition, he studied methods of developing high efficiency thermal power plants as well as the use of shock wave and expansion waves in novel propulsion and chemical production systems. Walter KISTLER, a Swiss-born U.S. physicist and inventor, and HERTZBERG developed miniature high-frequency acceleration-compensated quartz pressure sensors with microsecond response time. This research spearheaded the development of shock tube technology crucial to studying the sort of aerodynamic shock waves that spacecraft can encounter during reentry.

In 1966, HERTZBERG was appointed as professor of aeronautics and astronautics, and director of the Aerospace Research Laboratory (ARL) at the University of Washington (ARL was later renamed as the Aerospace and Energetics Research Program, or AERP). In addition to continuing his pioneering work on high power lasers, he engaged in research on laser applications, the study of novel propulsion systems, advanced fusion concepts, and expanded his work on the use of shock waves in chemical production systems. In addition, he developed new concepts in areas such as hypervelocity launchers (the ram accelerator) and automobile propulsion (cryogenic engines). He retired in 1993 but remained active in research until shortly before his death in March 2003. HERTZBERG was the author of more than 100 papers in the fields of gas dynamics, physics of high temperature gases, lasers, space launchers, cryogenic automobile propulsion, and other novel concepts. He also held numerous U.S. patents in these fields.

In addition to his research efforts at the University of Washington, HERTZBERG also immersed himself into the academic life of the department, teaching a variety of courses, serving on numerous committees, and engaging in public outreach. In 1970, he began to offer a yearly special topics graduate course in which he and his students explored many areas of emerging interest, such as the energy crisis, the green revolution, developments in automobile technology, space power systems, efficient energy conversion technologies, beamed power via lasers, *etc*. This was the course for which he was best known, and from which several major funded research programs sprang. In 1979, HERTZBERG initiated the undergraduate senior capstone design course in space systems engineering. Generations of students, both graduate and undergraduate, benefited from his unique teaching style, which combined creativity and humor with rigor and high expectations.

HERTZBERG was also a prolific and much sought-after consultant to industry and government. Among the companies and institutions for which he consulted over the years were Boeing Scientific Research Laboratory; G.E. Missiles & Space Division; Aerospace Corporation; S.T.I. Optronics, Inc. (formerly Mathematical Sciences Northwest, Inc. which he helped found in 1969); Rockwell International; Lockheed Missiles & Space Co.; Brookhaven National

Laboratory; Los Alamos National Laboratory (LANL); Pratt & Whitney; Olin/Rocket Research; and Kistler Aerospace Corporation.

HERTZBERG served on numerous professional and governmental committees and also on the NASA Research and Technology Advisory Council and the USAF Scientific Advisory Board. He chaired the Fluids Subcommittee of the National Research Council Survey of Plasma Physics and Fluids (1983–1984) and was a member of the LANL Advisory Committees (1984–1993). He was a member of the American Physical Society Directed Energy Weapons Study Group (1984–1986), and, beginning in 1978, served on the NASA Space Systems and Technology Advisory Committee. He was also a Fellow of the American Institute of Aeronautics and Astronautics (1976), an elected Fellow of the International Academy of Astronautics (1987), Fellow of the American Association for the Advancement of Science (1995), an elected member of the National Academy of Engineering (1976), and a member of the American Physical Society and Sigma Xi. He was the AIAA Dryden Medallist and received the AIAA Plasmadynamics and Lasers Award (1992). He was Lecturer (1977) and Visiting Lecturer (1983, 1988) at the Chinese Academy of Sciences, Beijing, and Paul Vieille Lecturer at the International Symposium on Shock Tubes and Waves (1969, 1989). In 1996, he presented the First Memorial Lecture to honor Prof. Irvine I. GLASS in Toronto, Canada.

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PICTURE. Taken in 1994. Courtesy Dept. of Aeronautics and Astronautics, University of Washington, Seattle, WA.

NOTE. The biography was kindly provided by Prof. Adam P. BRUCKNER of the University of Washington. A more detailed biography is available in Paper AIAA 2006-0335, *see* above.

HOPKINSON, Bertram (1874–1918)

▪ British mechanical and aeronautical engineer; pioneer of dynamic materials testing

Bertram HOPKINSON was born in Birmingham, U.K. He was the eldest son of John HOPKINSON (1849–1898), an engineer, manager, and inventor renowned for the construction of dynamo machines. Stimulated at a young age by his father's professional activities and ways of thinking, he studied mathematics and engineering at Trinity College (1891–1896). He was trained as a patent lawyer until his father's death (1898), at which point he decided to carry on his father's work in engineering and technological education. However, in later years he continued his practice in the law courts together with his research.

When he was appointed chair of the Mechanism and Applied Mechanics Department at Cambridge University (1903–1918), he also took over the supervision of the Cambridge Engineering School, which was part of the University, and became editor of the serial *Cambridge Engineering Tracts*. His main interest was in developing research in the department, with the aim of making it comparable with that of experimental physics at the Cavendish Laboratory. He built up a team of researchers looking at the science of flames and explosions as well as the impact of bullets on steel plates. Among his research students was Harry RICARDO, an engineer who made a name for himself with his pioneering work on internal combustion engines. It was HOPKINSON who encouraged RICARDO to work on engines, turning him from the more traditional pursuit of civil engineering at that time. Starting out with investigations in gas engines and petrol motors, HOPKINSON studied gas explosion phenomena and invented a recording calorimeter for explosions (1906) and an electrical thermometer for measuring gas engine temperatures (1907). He designed instruments to measure the rate of loss of heat through the walls of the reaction vessel (1906) and the emitted radiation (1910). Based on his expertise in explosion he became, together with Sir Dugald CLERK, secretary of the British Association Committee on Gaseous Explosions.

Accepting a fellowship offered to him by King's College, Cambridge (1914), HOPKINSON studied the mechanical strength of metals and designed a high-speed fatigue tester for investigating metal alloys under alternating stresses. Later he extended his studies to high-rate loading, such as that produced by placing high explosives in close contact with the test sample or impacting it with supersonic bullets. To determine the nature of the pressure-time profile when an explosive is detonated or when a projectile impinges on a hard surface, he invented an apparatus that has become known as the "Hopkinson pressure bar" (1914) – a derivative of the ballistic pendulum – which became a standard piece of equipment in the dynamic testing of materials. It uses a cylindrical bar where the length of the pulse is great compared with the radius of the bar. This method was further developed into the so-called "split Hopkinson bar" (1949) by Herbert KOLSKY, a U.S. professor of applied physics, who used two bars with the sample under investigation situated in between. On the outbreak of World War I, HOPKINSON, who obtained a commission in the Royal Engineers, applied his knowledge of explosions to problems of both attack and defense and worked on the best form of bomb to drop from aircraft. He also suggested an additional outer shell to the hull – a so-called "blister" – for the protection of warships from the effects of mines and torpedoes. To test his concept, he began to model dynamic phenomena in small-scale experiments, leading to his so-called "Law of Comparison." As an important result of such studies he formulated his famous "cube-root scaling law" (1915) – also known as the "Hopkinson scaling law." He established an experimental station for the Royal Flying Corps, where testing of aircraft was under his control. For example, he performed for the Air Force model tests on a one-sixth scale to optimize proportions of bomb-case weight to weight of explosive as well as the best material for bomb cases (1915).

HOPKINSON piloted a small plane himself to quicker communicate between Cambridge and his experimental station on the east coast, and he died in a flying accident in bad weather near London (1918). He was a Fellow of the Royal Society (from 1910) and a professional Fellow of King's College (from 1914).

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PICTURE. From *The scientific papers of Bertram HOPKINSON.* Cambridge University Press (1921). Reprinted with permission of Cambridge University Press, Cambridge, U.K.

HUBBLE, Edwin Powell (1889–1953)

▪ U.S. astronomer; founder of modern extragalactic astronomy

Edwin P. HUBBLE was born in Marshfield, MO to John Powell HUBBLE, a lawyer. His early interest in astronomy was sparked at the University of Chicago by the astronomer George E. HALE. After having earned an undergraduate degree in both mathematics and astronomy (1910), he turned away from astronomy and studied law at the Oxford University (1912). However, soon after he dissolved his practice and returned to the University of Chicago, where he again focused on astronomy at Yerkes Observatory in Wisconsin. In 1917, he earned a Ph.D. in astronomy with a focus on faint nebulae using photography as a diagnostic tool. After serving in World War I, he settled down to work at Mount Wilson Observatory (now part of the Hale Observatories) and began studying planetary nebulae, nebulous stars, novae, and stars variable in light with a 60-in. telescope, objects that are all within our own galaxy. Using the Hooker 100-in. telescope at Mount Wilson Observatory, then the largest optical instrument in the world, he observed that not all nebulae in the sky are part of the Milky Way, but rather that some are located outside – at least out to the extreme range of the largest telescopes, a billion or more light-years away. In 1924, HUBBLE announced the discovery of the presence of Cepheid variables in *extragalactic nebulae*, a term that he coined, later called by astronomers "galaxies." He established that the majority of observed nebulae are very far away from our Milky Way galaxy and that most likely they, too, are galaxies. After their classification into four principal types according to luminosity, degree of concentration, degree of diffuseness, and form (1925) – a classification still widely used today – he recognized that rotational symmetry about a dominating nonstellar nucleus was an almost universal characteristic of extra-galactic nebulae. Using spectroscopy to determine the motion in the line of sight, he observed, with the cooperation of Milton L. HUMASON, a systematic displacement toward longer lines in the spectra of distant objects. The so-called "Hubble relation" correlates spectral red shift with distance. The two astronomers made the surprising observation that these galaxies are apparently receding from ours and that the further away they are, the faster they are receding (1929). According to this so-called "Hubble law," the velocity of recession v is directly proportional to distance D; *i.e.*, $v = H_0 D$, where H_0 is the "Hubble constant" or "Hubble parameter" at the present epoch in the history of the Universe. In his book *The Realm of Nebulae* (1936) HUBBLE described in a semipopular form the results of his special researches. With the availability of more powerful telescopes in the late 1940s, it became obvious that HUBBLE's cosmic distance scale had to be stretched by at least a factor of 5.

During World War II, HUBBLE, who had already served as a line officer in World War I, was chosen by the Army Ordnance because it was believed that "ballistics has a curious affinity with astronomy" as he himself once described his assignment. He became chief of the Exterior Ballistics Branch of the Ordnance Research Laboratory at Aberdeen Proving Ground in Maryland and served as director of the Supersonic Wind Tunnel Laboratory. He "found out … ballistics was both underdeveloped and highly classified … The place is not the home of genius, but it knows the answers to many problems and how to get the answers for others" (Biogr. Mem. Natl. Acad. Sci. **41**, 182). He remained at BRL until

1946, after which time he returned to the Mt. Wilson Observatory and resumed his astronomical research. He greatly assisted in the design of the 200-in. Hale Telescope and served as chair of the Mt. Wilson Observatory Advisory Committee planning the building of the Palomar Observatory.

HUBBLE did not contribute to shock wave physics directly, but his observed phenomenon of expansion spurred others to propose expanding world models (*e.g.*, Alexander FRIEDMANN and Georges LEMAÎTRE), on calculating the age of the Universe (Edward A. MILNE), and the mechanism of its origin (George GAMOW). The Big Bang theory of other scientists, which he supported by his research results, stimulated the theoretical treatment of huge astrophysical explosions and shock waves resulting in the new branch of cosmic gas dynamics, and the numerical modeling of cosmogony.

HUBBLE was a member of many astronomical societies and the recipient of numerous honorary degrees. For his contributions to cosmogony he was awarded numerous gold medals, and for his defense work in World War II he received the Medal of Merit. The NASA/ESA *Edwin P. Hubble Space Telescope,* a giant 11.5-ton telescope placed in low-Earth orbit in order to make observations above the turbulent atmosphere, is named in honor of him. The *Hubble Award* established by the Advanced Imaging Conference (AIC) recognizes outstanding contributions to the art and science of astronomical imaging (since 2006).

Astronomers named a crater on the near side of the Moon and a minor planet (asteroid 2069 HUBBLE) after him.

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PICTURE. Courtesy The Observatories of the Carnegie Institution of Washington, Pasadena, CA.

HUGONIOT, Pierre-Henri (1851–1887)

▪ French physicist and applied mathematician; cofounder of modern shock wave theory

Pierre-Henri HUGONIOT was born in Allenjoie (Dépt. Doubs). The second son of Pierre HUGONIOT, a metallurgist, he showed an early talent for mathematics. At the age of 17 he was nominated *Préparateur de Physique* in the Strasbourg Faculty of Science. After graduating first in his class at the Ecole Normale Supérieure in Paris, he studied at the Ecole Polytechnique (1870–1872). Thereafter, he was accepted into the marine artillery service and became professor of mechanics and ballistics at the Ecole d'Artillerie de la Marine at Lorient, Brittany (1879–1882) and assistant director of its Central Laboratory (1882–1884). In 1884, he was appointed captain. His first research, done in collaboration with Hippolyte SÉBERT and relating to the effect of powder gases on the bore of a weapon (1882), was still based on treating the discontinuous flow as an adiabatic process using POISSON's law. Based on his assistance to Prof. Felix HÉLIE on the latter's book *Traité de balistique expérimentale* (Paris 1864), a report on ballistic experiments carried out by the French artillery at Gâvres, Brittany in the period 1830–1864 which earned them an award from the Paris Academy of Sciences, HUGONIOT was appointed *Répétiteur de mécanique* at the

Ecole Polytechnique (1884–1887). There he established the fundamentals of the theory of compressible, discontinuous flows (*i.e.*, of shock waves). In subsequent years, he treated the problem of discontinuous flow on a more general basis and, applying the law of conservation of energy to the pressure jump, he obtained for the first time a dynamic pressure-density relation for shock compression, a "dynamic adiabat," later called the "Hugoniot curve" or, "Hugoniot" for short. Furthermore, he demonstrated that for a perfect gas of constant ratio of specific heats γ, the maximum possible compression by a shock wave is given by the quotient $(\gamma+1)/(\gamma-1)$.

Little is known about HUGONIOT's personal life. According to the *Grand Larousse Encyclopédique* (1963 edition), he also worked on the mechanics of steam turbines, and he apparently also served as a consultant on this subject. The French mathematician Roger LIOUVILLE edited posthumously HUGONIOT's famous paper *Mémoires sur la propagation du mouvement dans un fluide indéfini.* In his obituary LIOUVILLE reported that HUGONIOT died on a business trip to the Compagnie des Tramways de Nantes. HUGONIOT, possibly consumed by his numerous tasks, passed away at the early age of 36.

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PICTURE. © Collections Ecole Polytechnique, Paris. The picture is part of a group photo showing HUGONIOT among his fellow students; it was taken on the occasion of their promotion in 1870. There also exists another picture of HUGONIOT (possibly the only other that has survived), showing him in a more advanced age and reproduced in the *Grand Larousse Encyclopédique.* Librairie Larousse, Paris (1962), vol. 5, p. 983. Unfortunately, its source is not given there.

NOTE. The library of the Ecole Polytechnique keeps 43 letters received by HUGONIOT in the period 1883–1886.

HUTTON, Charles (1737–1823)

▪ British mathematician, military engineer, and scientific writer

Charles HUTTON was born in Newcastle upon Tyne. He was the youngest son of Henry HUTTON, an overseer in a local colliery. He worked for a short time as a hewer in a pit at Longbenton in Northumberland, but since he acquired a taste for books, it was decided that teaching was his proper occupation. Largely self-educated, he began to teach mathematics and natural philosophy at his own Writing and Mathematical School, which he established

in Newcastle (1760). Contributing to engineering problems, land survey, and mathematical education, he wrote several tracts and textbooks such as *The Schoolmaster's Guide* (1764), an elementary textbook on arithmetic, his first publication; *A Treatise on Mensuration* (1767–1770), illustrated by the famous Thomas BEWICK, who established wood engraving as a major printmaking technique; *Plan of Newcastle and Gateshead* (1770), a local land survey of the city and its suburbs; and *The Principle of Bridges* (1772), a tract on the equilibrium of bridges.

Obviously based on his wide scope of interests in educational and scientific affairs, he was appointed professor of mathematics at the Royal Military Academy in Woolwich, southeast London (1773–1807). His researches centered on the convergence of series of experiments in ballistics, the building of bridges, and measurement of the mean Earth's density. In this fruitful period he wrote other renowned books on mathematics such as *A Course of Mathematics for the Cadets of the Royal Military Academy* (1798–1801), a two-volume textbook for his students at Woolwich; and the historical introduction to *Mathematical Tables* (1785), which contains the common, hyperbolic, and logistic logarithms. His *Mathematical and Philosophical Dictionary* (1795–1796), probably his bestknown work, contains a glossary of terms used in mathematics, astronomy, and natural philosophy as well as an interesting historical account of the rise, progress, and state of contemporary science. It has recently been reprinted in Germany (1973). He also edited a great many almanacs, including the *Ladies' Diary* (1773–1818), dealing with the popular mathematical and poetic sections of such books.

HUTTON contributed many papers to the *Philosophical Transactions*. For his investigations on *The Force of Fired Gunpowder and the Velocities of Cannon Ball* (publ. 1778) – along with the work of his countryman Benjamin ROBINS a milestone of modern internal ballistics as well as of supersonic aeroballistics – he received the Copley Medal (1778) of the Royal Society. Following in ROBINS' footsteps, he was the first to extend the ballistic pendulum technique to large-caliber (cannon) shots, as well as the first to verify the existence of supersonic muzzle velocities (1783). In addition, he first measured the aerodynamic drag ranging from subsonic to supersonic velocities and noticed that the power of the resistance-velocity law is not a constant. In the early 1800, HUTTON speculated on the origin of meteors ("stones that have fallen from the atmosphere…").

HUTTON also became renowned for his computation of the mean density of the globe (1778). After the British astronomer Nevil MASKELYNE had completed his series of observations at Mount Schiehallion, North Perthshire, to measure the attraction of mass by the deflection of a plumb line, HUTTON was chosen to deduce the corresponding estimate of the mean density of the globe. It was found that the mean Earth's density is 4.481 times that of water (modern value 5.517 g/cm^3). The French physicist and mathematician Pierre S. DE LAPLACE acknowledged the value of HUTTON's work in computing the density of the Earth in an article published in the French journal *Connaissance des Temps* (1823).

HUTTON retranslated into English EULER's German translation *Neue Grundsätze der Artillerie* (1745) of ROBINS' book *New Principles of Gunnery* (1742), which EULER had extended by numerous valuable comments. Corrected and enlarged, HUTTON's new edition (1805) of ROBINS' book became a basic source for most subsequent work on the theory of artillery and projectiles. His three-volume *Tracts on Mathematical and Philosophical Subjects* (1812) summarizes his most important contributions: it contains a treatise on various bridges and mathematical tables (vol. 1); calculations of the Earth's density (vol. 2); and a description of a new gunpowder eprouvette, new experiments to determine aerodynamic drag using a whirling machine, and a treatise on the theory and practice of gunnery (vol. 3).

HUTTON was made Fellow of the Royal Society (1774) and later served as its foreign secretary (1779–1783). He resigned from office upon the request of Sir Joseph BANKS, then president of the Society, who reproached him for not carrying out his duties efficiently. The University of Edinburgh awarded him the degree of doctor of law (LL.D. 1783).

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PICTURE. From HUTTON's *Tracts on mathematical and philosophical subjects.* T. Davison, London (1812), vol. 1, frontispiece.

HUYGENS [or Huyghens, Lat. *HUGENIUS*], Christiaan (1629–1695)

▪ Dutch physicist, mathematician, geometrician, optician, astronomer, and inventor; main contributor to the classical theory of percussion

Born in The Hague, The Netherlands, Christiaan HUYGENS belonged to a prominent family; his father Constantijn HUYGENS was a secretary to Prince Frederic Henry. He was supposed to continue the diplomatic tradition of his family and studied law at the University of Leiden (1645–1647) and at the College of Orange (1647–1649). However, influenced by the French philosophers Marin MERSENNE and René DESCARTES, who exchanged letters with his father, he began to study mathematics (1645) and eventually turned to the private study of nature (1650–1666). In 1666, he became one of the founding members of the Académie Royale des Sciences, and from that year lived mainly in Paris (1666–1681), where he met the German philosopher and mathematician Gottfried W. LEIBNIZ. Due to illness and political reasons he returned to The Hague, where he died in 1695.

HUYGENS made major contributions to mathematics, optics, and mechanics (particularly to statics and hydrostatics, and impact). He developed new optical techniques together with his brother Constantijn, formulated a wave theory of light, and applied geometrical optics to a number of optical systems. He improved the microscope and telescope and in 1655 discovered that the planet Saturn also has a large moon, now known as "Titan." Four years later he also discovered the true shape of the rings of Saturn. Studying fall and projectile motion in resisting media, he became convinced by experiments that the resistance in such media as air and water is proportional to the square of their flow velocity. He also cooperated with Denis PAPIN in building a *moteur à explosion* (1673).

Obviously dissatisfied with DESCARTES' treatment of percussion published in his *Principia Philosophiae* ("Principles of Philosophy," 1644), HUYGENS dedicated much of his time to studying the percussion of elastic bodies. Applying a geometrical treatment, HUYGENS worked out new rules of percussion that, confirmed in the course of discussions in Paris by repeated experiments and recorded in 1656 in his treatise *Tractatus de motu corporum ex percussione* ("On the Motion of Bodies by Percussion"), were published posthumously in 1703. His results were partly based on the principle that in any system of bodies the center of gravity could never rise of its own accord above its initial position. Asked in 1667 by Henry OLDENBURG, editor of *Philosophical Transactions*, to contribute to the problems of percussion, he submitted in 1669 a paper on this subject in which he briefly summarized his previous results. Most importantly, he found that during elastic percussion the sum of the products of the quantity of matter and the squares of the velocity is conserved, which in modern terms is the Law of Conservation of Kinetic Energy.

In his treatise *Horologium oscillatorium sive de motu pendulorum* ("The Pendulum Clock, or On the Motion of Pendulums," 1673), he thoroughly investigated the theory of the center of oscillation of compound pendulums – a difficult task that, already posed by the French mathematician and theologian Marin MERSENNE to the 17-year-old HUYGENS, had been previously grappled with in vain by renowned scholars of his time, such as the French mathematicians René DESCARTES and Honoratus FABRI. HUYGENS succeeded in formulating a general computation rule for determining the center of oscillation, applicable to all sorts of compound pendulums. The "center of oscillation" is identical to the "center of percussion," as was first noticed by the British mathematician John WALLIS.

In his book *Traité de la lumière* ("Treatise on Light," 1690), HUYGENS considered light as an irregular series of mechanical disturbances that propagate with very great, but finite, velocity

through the aether, a medium that supposedly consisted of uniform, minute elastic particles filling all of space. He considered light propagation therefore as a serial longitudinal displacement similar to a collision that, according to his concept, proceeds through a row of billiard balls: colliding particles produce around each particle new wave fronts – secondary spherical "wavelets" – that have the same speed as the overall wave. Thus, the observed wave front is the envelope of all fronts of the individual particles, the so-called "Huygens principle." This mechanistic wave model proved to be very successful in describing acoustic wave phenomena as was first shown geometrically by Christian A. DOPPLER in the case of a subsonically, sonically, and supersonically moving object (1846) and first proved experimentally with the discovery of the "head wave" phenomenon by Ernst MACH and Peter SALCHER (1886–1887). The Huygens principle was later extended by Augustin FRESNEL and Gustav KIRCHHOFF to explain interference and diffraction phenomena.

In the final years of his life, HUYGENS also discussed extraterrestrial life in a letter to his brother Constantijn, speculating that rational creatures live on each planet. This letter was published in Latin 3 years after his death as the *Cosmotheoros* (1698), further entitled (in translation) *The Celestial Worlds Discover'd: or, Conjectures Concerning the Inhabitants, Plants and Productions of the Worlds in the Planets*.

HUYGENS' output in mathematics (particularly in geometry, algebra, and calculus) and mechanics, optics, astronomy, and chronometry was enormous. Throughout his life he maintained an extensive correspondence with renowned contemporaries such as DESCARTES, LEIBNIZ, MERSENNE, OLDENBOURG, and WALLIS.

The *Christiaan Huygens Wetenschapsprijs* ("Christiaan Huygens Science Prize") of the Koninklijke Nederlandse Akademie van Wetenschappen (KNAW), the Dutch Royal Society, was established in 1998 and is awarded annually to researchers who have made a highly original contribution to a certain discipline.

Almost 350 years after HUYGENS' discovery of Titan, the scientific probe *HUYGENS*, since September 2004 orbiting Saturn on board the NASA/ESA/ASI CASSINI spacecraft, was released on December 25, 2004: after a 22-d journey to Titan it parachuted through its atmosphere and safely landed on its surface. Astronomers named a crater on Mars (*Huygens Crater*), a mountain on the near side of the Moon (*Mons Huygens*), and a minor planet (asteroid 2801 HUYGENS) after him.

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A list of HUYGENS' work published during his lifetime or as a consequence of his last will was provided by the Dutch Huygens Web, University of Utrecht; http://www.phys.uu.nl/~huygens/hug_biblio1_en.htm#top.

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PICTURE. By the Dutch print artist Frederik OTTENS, based on HUYGENS' portrait made by Gerard EDELINCK (1687) and prepared for publication of HUYGENS' *Opera varia* (1724). Courtesy Dibner Library of the History of Science and Technology, Smithsonian Institution Libraries. National Museum of American History, Washington, DC.

NOTE. In summer 1995, an International Congress on Christiaan HUYGENS was held in Leyden and Voorburg, The Netherlands, under the auspices of the Royal Netherlands Academy of Arts and Sciences and the Académie des Sciences of the Institut de France, Paris. The purpose of this major international Congress was to commemorate HUYGENS' life and work on the 300th anniversary of his death. *See* http://web.clas.ufl.edu/users/rhatch/pages/03-Sci-Rev/SCI-REV-Home/resource-ref-read/major-individuals/huygens/.

JOHNSON, William (1922–)

▪ British mechanical engineer; founder of the *International Journal of Mechanical Sciences* and the *International Journal of Impact Engineering*

William JOHNSON was born in Manchester, U.K. He was the elder son of James JOHNSON, a foreman in a wire-drawing plant. His early working-class education was at a high school and later in a mechanical engineering course at the Manchester College of Technology (later named UMIST), from which he graduated, B.Sc. (Hons), in 1943. After some minor work in engineering he was called up for service in the army in World War II, and in due course he became an officer in the Corps of Electrical and Mechanical Engineers serving until September 1947 in Italy and later in Austria. After demobilization he spent 2 years in the Civil Service but moved on to a lectureship in mechanical engineering and solid mechanics, first in Northampton Polytechnic, London, and later at the University of Sheffield, specializing in metal-forming plasticity theory in 1952. JOHNSON became a senior lecturer at Manchester University (1956–1960) and there continued his career work as a professor of mechanical engineering on slip-line theory with associated experiments. He also developed historical interests in science in these years, after attending courses at the University College, London, in the history and philosophy of science.

In 1959, he was invited to become founder and editor of the *International Journal of Mechanical Sciences* after suggesting the idea to the late Robert MAXWELL of Pergamon Press, Oxford; this monthly journal still flourishes today. For many years JOHNSON was also editor of the quarterly *Bulletin of Mechanical Engineering Education*. In 1984, at his suggestion, the *International Journal of Impact Engineering* was created, which is specifically devoted to problems in impact engineering. These journals are prominent international ones today, run by his former younger colleagues and researchers.

In 1975, JOHNSON was invited to a chair in mechanics in the Engineering Department at Cambridge University, retiring from there in 1982 but moving to fill a similar appointment in the United States at Purdue University in Indiana (1983–1989). Thereafter he visited and worked at many universities across the world, mostly with former colleagues. He was elected to a fellowship of the British Royal Society (1982) and later to the academies of India and Greece.

JOHNSON published (with coauthors) about 500 research papers and is the author of ten books, eight technical, one being an autobiography and the other a volume on the historical works of the British mathematicians and military engineers Benjamin ROBINS and Charles HUTTON, both of the latter appearing in 2003. The first of the eight editions above include *Plasticity for Mechanical Engineers* (1962, 1966) with Peter B. MELLOR; *The Mechanics of Metal Extrusion* (1962) with Hideaki KUDO; *Plane-Strain Slip-Line Fields* (1970, 1982) with Robert SOWERBY, James B. HADDOW, and Ronald D. VENTER; *Impact Strength of Materials* (1972); *Engineering Plasticity* (1973, 1986) with Peter B. MELLOR; and *Plasticity and Metal Forming* (1978) and *Crash-Worthiness of Vehicles* (1978), both with Athanasios G. MAMALIS. Many of the latter volumes have appeared in translation.

In the late 1950s, JOHNSON helped start the Department of the History of Science and Technology at Manchester University and a Medical Engineering Unit in 1973. He became attached to researching historically a number of British and continental scientists especially in his later years, particularly Jacques CASSINI, Martin FOLKES, James GLENIE, Charles HUTTON, Alfred MORDECAI, Benjamin ROBINS, Isaac TODHUNTER, and VOLTAIRE, about some of whom he wrote

several papers. He also addressed the early history of the ballistic pendulum and some monster guns and reviewed the contributions of American ballisticians, such as John A.B. DAHLGREN and Thomas J. RODMAN, to ballistic research.

Between 1965 and 1990 Prof. JOHNSON received several honorary degrees, prizes, and medals, most recently the History and Heritage Engineer-Historian Award of the American Society of Mechanical Engineers (ASME) for the year 2000 "for his many publications on a wide variety of technological-history subjects, including projectiles, the life and works of Benjamin ROBINS, manufacturing technology, and steam hammer forging."

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PICTURE. Courtesy Prof. emeritus W. JOHNSON, Cambridge University, Cambridge, U.K.

NOTE. This short biography was composed by Prof. JOHNSON and sent to the author in September 2005.

JOUGUET, Jacques Charles Emile (1871–1943)

▪ French engineer and mathematician; cofounder of the first theory on detonation

J.C. Emile JOUGUET was born in Bessèges (Dépt. Languedoc). His father was a mining engineer and director in the steel and iron industry. After schooling in Nîmes (1891) he studied at the Ecole Polytechnique and graduated as an engineer (Ph.D. 1889). He started his professional career as a railroad supervisor at Bordeaux (1895–1898), where he came under the influence of Prof. Pierre DUHEM and increasingly became involved in teaching. He was professor of general theoretical and applied mechanics (1898–1907) at the Ecole des Mines in Saint-Étienne (Dépt. Loire), *répétiteur de mécanique* (1809) at the Ecole Polytechnique, and professor of analysis, descriptive geometry, and topography (1910–1914) at the Ecole des Mines in Paris. In World War I, he served in the French Artillery as a lieutenant-colonel. In

the period 1920–1939, he taught in Paris and was professor of machines at the Ecole des Mines, professor of thermodynamics at the Ecole du Génie rural, and professor of mechanics at the Ecole Polytechnique, where he extended his teaching to mathematical analysis, thermodynamics, mechanical engineering, and topography. He also taught courses on theoretical and applied mechanics at the Ecole Nationale du Génie Rural in Paris.

Together with his friends and colleagues Jacques HADAMARD and Pierre DUHEM he belonged to the small group of leading French shock physicists who tackled many problems posed by this new discipline. Examples include various problems of similarity, the analogy between shocks in gases and hydraulic jumps, and propagation effects of shock waves in solids. Independently of the English physical chemist David Leonard CHAPMAN, he analytically formulated a theory of detonation, the so-called "Chapman-Jouguet (CJ) hypothesis" (1899–1905). Detonations with fronts advancing at sonic speeds – so-called "Chapman-Jouguet detonations" – are the most common. The region immediately behind a detonation wave is still referred to as the "Chapman-Jouguet zone."

Together with his colleague Louis CRUSSARD he investigated the stability of detonation waves and applied the Law of Similarity to its propagation (1907–1908). In his book *Mécanique des explosifs, étude de dynamique chimique* ("Mechanics of Explosives, a Study of Chemical Dynamics"), published in 1917, JOUGUET treated the fluid dynamical aspects of fast chemical reactions, such as detonation and deflagration, theoretically and in a very general manner. He also kept a steady interest in applying thermodynamics to mechanical engineering and contributed to the development of steam turbines and thermal engines.

JOUGUET became a member of the Académie des Sciences (1930) and commander of the Légion d'honneur (1936), and retired as Chief Engineer of Mines. He was a major contributor to the theory of detonation and the theory of shock waves.

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PICTURE. Bibliothèque de l'Ecole des mines de Paris, France.

KANT, Immanuel (1724–1804)

▪ German philosopher, physicist and cosmologist

Immanuel KANT was born in Königsberg, East Prussia (now Kaliningrad, Russia). He was the fourth of nine children of Johann Georg CANT, a harness maker of modest means. He attended the famous pietistic Collegium Fredericianum in Königsberg and thereafter began to study mainly physics and mathematics at the University of Königsberg (1740). Forced by financial circumstances, he interrupted his study and worked as a private tutor for a period of nine years. He resumed his study at the University of Königsberg, where he received his doctorate in philosophy and habilitated (1755). Working there first as an underpaid instructor (1755–1770), he became professor of logic and metaphysics (1770), a position he held until his retirement (1797).

KANT, more known for his many philosophical works, particularly his *Kritik der reinen Vernunft* ("Critique of Pure Reason," 1781), also speculated on the origin of earthquakes. From a historical point of view his contributions can be regarded as milestones in the evolution of seismology. One year before the 1755 Lisbon Earthquake, KANT finished his long memoir *Allgemeine Naturgeschichte und Theorie des Himmels* ("Universal Natural History and the Theory of the Heavens," published in 1755) in which he treats cosmology according to Newtonian principles. He speculated that the spiral nebulae are distant stellar systems comparable in size to our own stellar system and interpreted the Milky Way as a great disklike structure of a vast swarm of stars, all orbiting some common center or centers in a manner very similar to the planets orbiting around the Sun. KANT also suggested that the nebulae were other disk systems outside our Milky Way, which he called "island universes" – now known as "galaxies." His representation of our Milky Way was basically correct, and in 1993 a first direct proof was given by NASA's Cosmic Background Explorer (COBE) using high-resolution infrared digital imaging.

His theory of nebulae was taken up by Pierre-Simon DE LAPLACE in his Nebular Hypothesis of Earth's Creation (1796), which postulates that the Solar System was formed from a spinning cloud of gas. In the late 1920s, in a series of observations carried out by the U.S. astronomer Edwin HUBBLE, it was conclusively proved that indeed separate galaxies exist beyond our own – thus increasing the size of the Universe by a factor of more than 100. KANT tried to explain the origin of the Universe from a primordial chaotic state of matter, contrary to Sir Isaac NEWTON who had explained the Solar System in terms of a stationary state.

In 1756, KANT also wrote three papers on the Great Lisbon Earthquake that occurred on November 1 (All Saints' Day), 1755. He did not speculate on moral or theological aspects like many of his contemporaries such as François VOLTAIRE and Jean-Jacques ROUSSEAU but rather thoroughly collected all reported data on earthquakes available to him (he never left East Prussia throughout his life), compared existing earthquake theories, and analyzed them soberly also in regard to their possible quantitative effects. Despite these efforts, he eventually ended up, like some of his contemporaries, with an attempt to explain them by subterraneous fires and explosions quoting Nicolas LÉMERY's famous "model volcano" experiment. Since he was not an experimentalist, he probably never considered the simple practical aspect of how nature could have provided such huge quantities of pure sulfur and iron, closely positioned and initially separated, to create an oxyhydrogen explosion with dimensions of destruction on the scale of the Lisbon event. On the other hand, he first attributed the origin of water movements of those inland lakes that are not connected with the sea to either varying atmospheric pressure (a phenomenon later studied in more detail by the Swiss scientist François A. FOREL and called "seiches") or to ground motions as observed during the Lisbon Earthquake in several European lakes far from the epicenter. He also correctly attributed the origin of large surge waves observed during the Lisbon Earthquake that killed many people, later known as "tsunamis," to earthquake-induced displacements of the sea floor.

Although philosophical and theological aspects predominated KANT's later works, he maintained a close affiliation with the natural sciences. His treatment *Metaphysische Anfangsgründe der Naturwissenschaft* ("Metaphysical Foundations of Natural Science," 1786), reprinted three times until 1800, found a wide audience among natural scientists of all fields. Today he is widely considered the foremost philosopher since classical antiquity, effecting a revolution in philosophy and influencing the development of science, theology, and philosophy in a diverse manner.

Astronomers named a crater on the near side of the Moon after him.

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PICTURE. Steel engraving by Johann L. RAAB (around 1860), after a painting by Gottlieb DÖBLER (1791). In the public domain, taken from Wikipedia, the free encyclopedia;
http://en.wikipedia.org/wiki/Image:Immanuel_Kant_%28portrait%29.jpg.

KÁRMÁN, Theodore VON [born VON SKOLLOSKISLAKI KÁRMÁN Tódor] (1881–1963)

▪ Hungarian-born U.S. physicist, aerodynamicist, and applied mathematician; father of supersonic flight

VON SKOLLOSKISLAKI KÁRMÁN Tódor – who came to be known as "Theodore VON KÁRMÁN" – was born in Jozsefvaros, a suburb of Budapest, as the third son of VON SKOLLOSKISLAKI KÁRMÁN Mór (Maurice), a university professor of education. He already showed in his childhood a surprising talent for mathematics. Before entering university he won the Eötvös Prize for Hungarian secondary students in science and mathematics. After studying engineering at the Múegyetem (Royal Josephs Polytechnic) in Budapest (1903–1906), he received a 2-year fellowship from the world famous University of Göttingen (1906). Under the influence of the mathematicians Christian Felix KLEIN and David HILBERT he began to collaborate with Ludwig PRANDTL and Max BORN on various problems of aerodynamics and thermodynamics.

After his habilitation (1910) at the University of Göttingen with a thesis on solid-state mechanics, entitled *Untersuchungen über die Bedingungen des Bruches und der plastischen Deformation, insbesondere bei quasi-isotropen Körpern* ("Investigations on the Conditions of Fracture and Plastic Deformation, Particularly of Quasi-Isotropic Bodies"), he taught as a *Privatdozent* (university lecturer) in Göttingen (1910–1912) and at the Hungarian Mining College (1912–1913) in Schemnitz (now Banská Štiavnica, Slovakia). He began working on the mechanics of solid continua, in particular on the strength and elasticity of materials. For example, he studied the brittle-ductile transition in rock deformation and demonstrated in his famous experiments that sandstone (usually a brittle material) becomes ductile when subjected to uniform compression and deformation (1911).

Returning to Germany, he was appointed chair of the Mechanics and Aeronautics Department at the RWTH Aachen and became director of the Institute of Aerodynamics (1913–1934), which was interrupted only by his military service throughout World War I.

In 1926, he first made plans for setting up a laboratory for the study of supersonic motion at Aachen, which was opened in 1929. During the period 1926–1927, he spent some time at CalTech in Harry F. GUGGENHEIM's new aeronautical laboratory. In Kobe, Japan, he built a new wind tunnel, similar to the one in Aachen, for the aircraft division of the Kawanishi Works (1927). Upon returning to Aachen, he accepted an invitation from the president of CalTech to advise on the design of a wind tunnel (1926). In the following two years, he spent half his time at CalTech but in addition remained director of the Institute of Mechanics at the TH Aachen. In 1930, he accepted an offer from the U.S. physicist Robert A. MILLIKAN to become director of the Guggenheim Aeronautics Laboratory at CalTech (1930–1949). At CalTech he began to study supersonic air flows around projectiles of various shapes. Together with Norton B. MOORE, one of his doctoral candidates, he published a

remarkable paper on these results (1932) that significantly promoted research on supersonic aerodynamics in the United States. The method they developed was applied not only to projectiles but later also to the design of airplanes and all kinds of airplane components.

In 1936, VON KÁRMÁN became a U.S. citizen. His contributions, covering both sub- and supersonic flight and treating the theory of elasticity, boundary layer theory, heat transfer, turbulence, compressible fluids, and airfoil and propeller profiles, laid the theoretical foundations for modern aerodynamics. His ideas also influenced the design of the first aircraft to break the sound barrier, the Bell X-1. Probably his best-known achievement is the discovery of a special type of periodic vortex pattern of unsteady flow separation over bluff bodies, the so-called "von Kármán vortex street," which can cause detrimental periodic vibration effects on aircraft structures.

VON KÁRMÁN was a cofounder of the Aerojet Engineering Corporation (1942), the RAND Corporation (1948), and CalTech's Jet Propulsion Laboratory, now NASA-JPL. He also gave direction to the early stages of the American rocket and space program. Under his leadership NATO's Advisory Group on Aeronautical Research and Development (AGARD) established the Training Center for Experimental Aerodynamics (1956), located in Belgium at Rhode-Saint-Genèse. After his death, it was renamed the *Von Kármán Institute (VKI) for Fluid Dynamics*; the motto of the Institute, which houses three departments (aeronautics & aerospace, environmental & applied fluid dynamics, and turbomachinery & propulsion), is "Training in research through research." In 1959, serving as chief scientific advisor to the U.S. Air Force, the Gas Dynamics Facility at Arnold Engineering Development Center (AEDC), located in southern Middle Tennessee, was renamed *Von Kármán Gas Dynamics Facility (VKF)*.

VON KÁRMÁN edited the journal *Advances in Applied Mechanics* (vols. I–VIII, 1956–1964, publ. by Academic Press), which contains review articles of internationally renowned experts in the field of fluid mechanics and shock waves. He was awarded the Wright Brothers Trophy (1954), and President John F. KENNEDY awarded him the first Medal of Science (1963) to honor his contributions to science, technology, and education. In addition, he received many other honors and 29 honorary doctorates from various national and foreign universities and colleges.

Theodore von Kármán Medal, established and endowed in 1960 by the Engineering Mechanics Division of the American Society of Civil Engineers (ASCE), is awarded to an individual in recognition of distinguished achievements in engineering mechanics. The *von Kármán Award*, instituted in 1987, is the premier award of the International Academy of Astronautics (IAA) given annually to recognize outstanding lifetime achievements in any branch of science. The *von Kármán Lecture Series* is held at VKI and given by active international experts from universities, research establishments, and industry. In the 1990s, the *Kármán Tódor Wind Tunnel Laboratory (KTWTL)* at the Department of Fluid Mechanics of the Budapest University of Technology and Economics was established in his honor.

A crater on the far side of the Moon and a crater on Mars are named for him. On August 31, 1992, the U.S. Post Office issued the 29-cent von Kármán postage stamp featuring space exploration.

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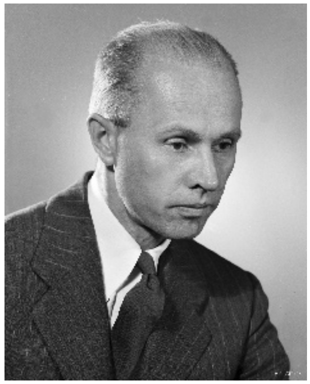
PICTURE. Courtesy Von Karman Institute (VKI) for Fluid Dynamics, Rhode-Saint-Genèse, Belgium.

KISTIAKOWSKY, George Bogdan (1900–1982)

▪ Ukrainian-born U.S. chemist and high explosives specialist



George B. KISTIAKOWSKY was born in Kiev, Ukraine, a province of pre-revolutionary Russia, to Bogdan KISTIAKOWSKY, a chemistry professor, and attended private schools in Moscow and Kiev. After spending two years as a Russian soldier in the White Army, he escaped to Germany where he studied chemistry at the University of Berlin. Here he took his Ph.D. (1925) with a thesis on the photochemistry of chlorine monoxide and ozone. His thesis supervisor was the famous chemistry professor Max BODENSTEIN, an authority on chemical equilibria, catalytic reaction kinetics, and chain reactions, who was a main inspiration for him to continue research in this field. In the following year, he emigrated to the United States and resumed research at Princeton University, NJ (1926–1930), where he was promoted to the rank of assistant professor (1928). At Harvard University (1930–1970) he became professor of chemistry and performed research on the mechanism of chemical reactions, thermochemistry, and the structure of molecules. His subject compounds varied from the simplest gases to highly complex biological species such as enzymes and antibodies, and his techniques covered sound waves, ultraviolet waves, spectroscopy, shock waves, nuclear magnetism, and scanning mass spectrometry. In 1940, he was called upon by the U.S. government to serve as an explosives consultant for the National Defense Research Committee (NDRC). He became head of the committee's explosives division (1942), presiding over the preparation, testing, and manufacture of new explosives and the development of gun and rocket propellants. During the period 1943–1945, he participated in the Manhattan Project. As head of the Explosives Laboratory at Los Alamos, NM he was responsible for manufacturing the high-explosive lenses for the implosion device (the "Gadget") used in the Trinity Test of the plutonium bomb (July 16, 1945). After World War II, he was engaged in research of chemical kinetics, shock waves, and molecular spectroscopy (1946–1970).

Beginning in the early 1950s, KISTIAKOWSKY and collaborators used the shock-tube technique over a period of 20 years to study chemical reactions and relaxation processes in gases and mixtures. He developed a soft X-ray densitometer with a resolution of a few microseconds to quantitatively resolve the density in the reaction zone of gaseous detonation waves. Using data obtained from mass spectroscopic and gas conductivity probes he derived dissociation energies of H_2, N_2, CO, and CO_2, rate constants of free-radical reactions, and information of isotropic exchange between oxygen atoms and CO_2 and SO_2. He also studied the chemical kinetics of many high-temperature homogeneous reactions, including (1) the decomposition of N_2O; (2) the polymerization, decomposition, and oxidation of acetylene; and (3) chemiluminescence and chemi-ionization. Using spectroscopic methods he identified free radicals, their vibrational and rotational temperatures, and reaction rates. His biographer, the British chemist Sir Frederick DAINTON, F.R.S., appropriately wrote, "Nowhere is his experimental virtuosity and firm grasp of physico-chemical principles more evident than in a long series of papers on gaseous detonation."

KISTIAKOWSKY was a member of the Science Advisory Committee of the U.S. President (1957–1964) and Special Assistant to the President for Science and Technology (1959–1961). He received the President's Medal for Merit (1946), the Nichols Medal (1947), the Willard Gibbs Medal (1960), the President's Medal of Freedom (1961), the Bernard Lewis Medal (1962), the Parsons Medal (1963), the T.W. Richards Medal (1968), the Priestley Medal (1972), the Peter Debeye Award (1974), and a number of other medals and prizes. He was a member of the National Academy of Sciences and a foreign member of the Royal Society of London and received 13 honorary doctorates from various universities and colleges.

Since 1971, a *George B. Kistiakowsky Memorial Lecture* has been given annually at the Dept. of Chemistry and Biology of Harvard University by notable individuals in physical chemistry.

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PICTURE. Dated 25 July 1947. Courtesy Los Alamos National Laboratory Archives, Los Alamos, NM.

KOBES, Karl (1869–1950)

▪ Austrian engineer and university administrator

Karl KOBES was born in Vienna and studied civil and mechanical engineering at the K.u.K. Polytechnisches Institut Wien (now TH Wien). After a 9-year period in praxis, he returned to the Polytechnic Vienna (1898) and became a university lecturer (1901), associate professor (1902), and full professor of theoretical mechanics occupying the Chair of Theoretical Mechanical Engineering (1905). In the late 1900s, he studied the problem of friction in bearings of high-speed turbines, performed power measurements on diesel engines, and determined the efficiency of belt drives. His most original contribution was certainly the investigation of the mechanism of air brakes. KOBES demonstrated that air brakes could be actuated more efficiently with a velocity exceeding the sound velocity in air, which in practice could be very important in the case of long railway trains. Based on previous works of Bernhard RIEMANN, Pierre-Henri HUGONIOT, and Gyözö ZEMPLÉN, he published in 1910 the first shock-tube theory, which was later resumed in Berlin by Friedrich HILDEBRAND at the Knorr-Bremse AG in 1927 and Hubert SCHARDIN at the Luftkriegsakademie (Air Force Academy) in 1932.

In order to improve the level of education and to better match it to practical needs, he later reorganized the courses of instruction at the Polytechnic Vienna by asking leading authorities in industry and transportation to cooperate in the state board of examiners. He was appointed dean of the Faculty of Mechanical Engineering (1913–1915) and served as president of the Polytechnic Vienna (1919–1920). After his retirement (1935) he became a privy councilor. In 1944, he became Honorary Senator of the TU Vienna.

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PICTURE. Courtesy Archive of the Technical University of Vienna, Austria.

LAMB, Sir Horace (1849–1934)

▪ British mathematician and fluid dynamicist

Sir Horace LAMB was born in Stockport, Cheshire to John LAMB, a cotton-mill foreman. After attending the grammar school in Stockport, he won a scholarship in classics at Queen's College in Cambridge (1867) but declined the scholarship to spend a year at Owens College, a part of Victoria University (now University of Manchester), where he prepared for a mathematical scholarship. He entered Trinity College (1868), where his teachers were George STOKES and James C. MAXWELL. He graduated there as Second Wrangler (1872). In the same year, he was awarded a Smith's Prize and made a Fellow and Lecturer at Trinity College.

After a 3-year period as a lecturer at Trinity College (1872–1875), he went to Australia as the first professor of mathematics at the University of Adelaide (founded in 1874). He returned to England (1885) and became professor of pure mathematics and later of pure and applied mathematics at Owens College, where he stayed until his retirement (1885–1920). On his retirement from Manchester, LAMB returned to Cambridge, where Trinity College made him an Honorary (Rayleigh) Lecturer (1920–1934).

LAMB was an excellent teacher and noted for his writing abilities. He wrote many articles on mathematics, mostly published in the *Proceedings of the London Mathematical Society* and in his book *Elementary Course of Infinitesimal Calculus* (1897). Today he is considered one of the greatest contributors to applied mathematics. Interested in particular in fluid dynamics and the application of analysis to those physical phenomena in which wave transmission is a central feature, he worked on tidal waves, acoustics, earthquake tremors, hydrodynamics, and underwater explosions. For example, he extended Lord RAYLEIGH's work on the vibration of shells (1891) and analyzed the waves produced in an elastic solid by an impulse of short duration (1904). Here he showed that a localized impulse could separate itself out into a number of disturbances of different types that travel at different speeds.

In his book *The Dynamic Theory of Sound* (1910) he gives a comprehensive mathematical treatment of the physical aspects of sound, covering the theory of vibration, the general theory of sound, and the equations of motion of strings, bars, membrans, pipes, and resonators.

LAMB first studied the deformation of an impulsively loaded plate, which could not be determined directly using conventional bending theory (1917). To understand how earthquake tremors are transmitted around the globe, he studied the propagation of waves on the surface of an elastic solid ("Lamb waves") and investigated the seismic effects of vertical loading on the Earth's surface (1917). Other topics he worked on include electrical induction, electric waves, and the absorption of light. He also wrote textbooks entitled *Statics* (1912), *Dynamics* (1914), and *Higher Mechanics* (1920), a treatise on *The Dynamical Theory of Sound* (1910), the article *Analytical Dynamics* for the supplement to the *Encyclopaedia Britannica* (1902), and the article *Akustik* for the German *Encyclopädie der mathematischen Wissenschaften* (1906).

For the British Aeronautical Research Committee (ARC) he made studies of airflow over aircraft surfaces (1921–1927). He also treated analytically in greater detail than had hitherto been done the bubble dynamics of an underwater explosion (1923), a phenomenon that apparently was first investigated theoretically and experimentally by the German military scientist Rudolf BLOCHMANN (1898). LAMB's famous textbook *Hydrodynamics*, which originated from his courses of lectures given at Cambridge and completed in Adelaide under the title *Treatise on the Mathematical Theory of the Motion of Fluids* (1878), has meanwhile undergone eight editions of which the first six were largely revised and extended by himself over a period of 53 years. It became a standard work on fluid dynamics and wave theory on which many subsequent underwater shock physicists, aerodynamicists, and seismologists have based their work. In this book, he also treated problems of discontinuous wave motion such as tidal and aerial waves of finite amplitude; for the latter, however, he did not use the term *shock wave*.

LAMB was twice vice president of the Royal Society, which awarded him its Royal Medal (1902), and president of the British Association (1925) and the London Mathematical Society (1902–1904). He received also the De Morgan Medal (1911), the London Mathematical Society's premier award, and the Copley Medal (1923) of the Royal Society of London. He was knighted in 1931. In Australia his name is perpetuated by the *Horace Lamb Lecture Theatre* at the University of Adelaide and by the *Horace Lamb Centre for Oceanographic Research* at Flinders University, Adelaide.

A crater on the far side of the Moon is also named after him.

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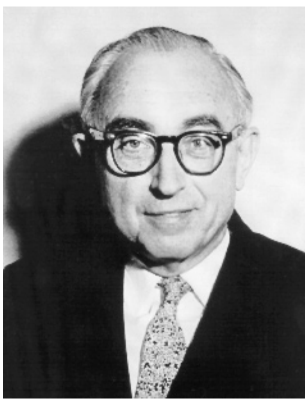
PICTURE. Courtesy University of Adelaide Archives, Adelaide, Australia.

LAPORTE [or LAPORTE], Otto (1902–1971)

▪ German-born U.S. physicist



Otto LAPORTE was born in Mainz, Germany as the son of Wilhelm LAPORTE, a heavy-artillery officer in the Imperial German Army. He studied at the Universities of Frankfurt/Main (1920) and Munich (1921–1924). In Munich he came under the influence of Prof. Arnold SOMMERFELD, renowned for his book *Atombau und Spektrallinien* ("Atomic Structure and Spectral Lines," 1919). LAPORTE worked theoretically on the structure of atoms and analyzed measured spectra of vanadium (1922) and iron (1924), thereby discovering the fundamental principle that earned him his Ph.D. (1924). It classifies the atomic energy states into two types, today among spectroscopists known as the "Laporte rule."

With a recommendation from Prof. SOMMERFELD, he went to the United States on a postgraduate fellowship and worked for the National Bureau of Standards (NBS) in its spectroscopy section (1924–1926), coming for the first time into close contact with experimental spectroscopy. At the University of Michigan in Ann Arbor he became a faculty member and instructor of theoretical physics (1926–1927) and professor of physics (1927–1971). In addition, he lectured at NBS and was a visiting professor at Kyoto Imperial University (1928), Tokyo Imperial University (1933), and the University of Munich (1937). After the war LAPORTE worked as an intelligence analyst in the European command of the U.S. Army of Occupation at Heidelberg (1949–1950). In 1944, he entered the field of fluid dynamics and calculated the lift of an airfoil of elliptical outline. Two years later he entered shock wave physics when a member of the Michigan faculty left the university, leaving behind an unfinished project. LAPORTE, almost simultaneously with Prof. Arthur KANTROWITZ, recognized that the shock tube is a superb tool for the study of high-temperature phenomena in gases, because the gas temperature can be raised by a shock and maintained for a brief period of time. LAPORTE assumed charge of the Shock Tube Laboratory at the University of Michigan and initiated research on reflected shock waves (1951), which he first applied to produce high local temperatures. This enabled him not only to enter temperature regions hitherto inaccessible by stationary methods but also to promote high-speed spectroscopic diagnostics.

Besides his research and teaching activities, he acted temporarily as a science attaché with the American Embassy in Tokyo (1954–1956, 1961–1963). Soon speaking fluent Japanese, he became a profound connoisseur of the Japanese culture and assisted in securing the agreement between the United States and Japan on the uses of atomic energy. LAPORTE was one of the charter members of the Division of Fluid Dynamics of the American Physical Society (APS), briefly also serving as its chairman (1965). In 1971, LAPORTE was elected posthumously to the National Academy of Sciences (NAS) of the United States.

In recognition of his scholarship and early guidance the American Physical Society (APS) Division of Fluid Dynamics established the *Otto Laporte Memorial Lectureship*, to be given annually. The *Otto Laporte Award* of APS recognizes outstanding research accomplishments pertaining to the physics of fluids. In addition, at each International Symposium on Shock Waves a distinguished scientist presents the *Otto Laporte Lecture* as the final plenary lecture.

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PICTURE. Courtesy Dr. H. REICHENBACH, EMI, Freiburg, Germany.

LAVAL, Carl Gustaf Patrik DE (1845–1913)

▪ Swedish engineer, inventor, and industrialist

C. Gustaf P. DE LAVAL was born in Orsa, a town in the Swedish province of Dalarna, and came from a Swedish noble Protestant family that had emigrated from France after

the massacre of St. Bartholomew (1572). In the period 1863–1866, he studied and graduated at the newly organized Stockholm Institute of Technology, in 1877 renamed the Royal Institute of Technology (Kungliga Tekniska Högskolan, KTH). First working for the Swedish mining company Stora Kopparberg, he decided to continue his education and attended the University of Uppsala. After taking his doctorate in chemistry there (1872), he founded a sulfuric acid factory in Falun (1873) but soon went bankrupt and continued working at Stora Kopparsberg. In 1875, he worked as a metallurgical engineer in the iron works of Klosterbruck, a town in the province of Moravia, then a part of the Austro-Hungarian empire.

DE LAVAL invented various types of centrifuges; one of the best known was his cream separator (1878), which came into use in around 1880. Based on the large demand for cream separators, he founded the company AB Separator (1883). The centrifuge was driven by his first steam turbine (1883) and quickly adapted in the larger dairies for butter making. DE LAVAL's first steam turbine (Swed. *Ångturbin*) consisted of a single wheel operating at 30,000 rpm. His most renowned invention, the so-called "Laval nozzle" (1888) with its divergent exit geometry, allowed for the first time supersonic outflow velocities without detrimental choking, which immediately improved the efficiency of steam turbines. In 1893, DE LAVAL displayed his single-stage steam turbine at the World Columbian Exposition in Chicago. Today this turbine type is part of the collection of the Smithsonian Institution of Technology in Washington, DC and of the Deutsches Museum in Munich.

DE LAVAL's concept of the Laval nozzle, established by intuition rather than by scientific investigation, was later adapted by many researchers and proved to be very useful not only in supersonic aerodynamics but also in rocketry, pulsejet engines, and wind tunnel testing. DE LAVAL also performed aerodynamic drag studies of air foils and propellers using a wind tunnel; however, he did not publish these studies. His numerous notebooks and drawings are kept at the archives of the Technical Museum in Stockholm.

The extremely high revolution of the turbine wheel required special constructions of the bearings and gearing, which led to revolutionary solutions. To eliminate dangerous wobbling at high speeds, he used a thin and elastic axle for the turbine wheel, a novel concept for which he also obtained international patents (1889, 1891/1892). For purposes other than centrifuge propulsion that required a lower revolution, he designed a high-precision double-helical gear. As early as 1895 more than 37 companies and enterprises were using his patents and inventions. DE LAVAL's first factory of steam turbines, founded in 1890, was transformed three years later into a corporation, the AB de Lavals Ångturbin.

DE LAVAL also contributed with his ideas to other industrial fields, and today he is considered one of the early pioneers of Sweden's industry. In acknowledgment of his contributions to steam turbines he received the Grashof Gold Medal (1904) from the Verein Deutscher Ingenieure (VDI). In 1912, DE LAVAL became a Honorary Member of the American Society of Mechanical Engineers (ASME). In 1957, a series of *De Laval Memorial Lectures* was established by the Royal Swedish Academy of Engineering Sciences in order to commemorate DE LAVAL's contribution to the development and applications of steam turbine machinery.

ORIGINAL WORKS. His Swedish patents that could be connected to the Laval nozzle are: *Turbine,* No. 325 (1883) — *Method to manufacture turbines,* No. 430 (1885) — *Steam inlet channel for rotating steam engines,* No. 1,902 (1888) — *Nozzle for steam or gas turbines,* No. 6,610 (1894) — *Device at steam turbine discs,* No. 24621 (1907).

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PICTURE. In the public domain, taken from Wikipedia, the free encyclopedia; http://de.wikipedia.org/wiki/bild:GustafDeLaval.jpg.

NOTE. The author acknowledges the assistance of Prof. Stig BORGLIN, TH Lund, Sweden, for providing worthwhile references on DE LAVAL's nozzle invention.

LE BOULENGÉ [or LEBOULENGÉ], Paul-Emile (1832–1901)

▪ Belgian army-officer and inventor

Paul-Emile LE BOULENGÉ was born in Mesnil-Eglise in the province of Namur, Wallonia and educated at the Ecole Royale Militaire in Brussels (1850–1853). Thereafter, he embarked upon a military career in the Belgian artillery (1853–1859). In the early 1860s, LE BOULENGÉ invented his *clepsydre électrique*, a chronograph for measuring the velocity of artillery projectiles which in respect of accuracy and practicability surpassed Col. Auguste J.A. NAVEZ's electroballistic pendulum (1853). This instrument also allowed one to measure the trajectory time; *i.e.*, the free-flight duration that the projectile covers between leaving the muzzle and impacting the target. Later on, LE BOULENGÉ, improving the NAVEZ chronograph, used two falling rods: the first one was released electromagnetically by the projectile at the moment of leaving the muzzle, and the second rod was released after a certain time, when the projectile, interrupting in free flight the current of a second coil, released a second falling rod that marked this time instant with a sharp knife at the periphery of the first falling rod. This instrument, the so-called "Le-Boulengé chronograph," was used up to the end of World War I in most ballistic laboratories, both in Europe and overseas, particularly in Japan, Brazil, and Peru. Measured data on projectile velocities were also useful to obtain insight into drag effects as function of the projectile geometry. In the 1870s, he also invented an acoustic telemeter.

After being detached temporarily to the Ecole Pyrotechnique, Antwerp (1859–1867), he became a member of the operation staff of the artillery (1867) and was deputized to inspect military weapons.

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PICTURE. Courtesy Head Documentation Center, Royal Army and Military History Museum, Brussels, Belgium.

NOTE. LE BOULENGÉ's contribution may stand here only as an example of attempts made by many other contemporary and subsequent inventors of chronographs to improve the time resolution of diagnosing high-speed phenomena. The development of precision chronography was decisive for scientific progress in understanding the basics of interior and exterior ballistics as well as of shock and detonation wave phenomena and their technical applications.

LE CHATELIER, Henry Louis (1850–1936)

▪ French chemist, metallurgist and engineer

Henry L. LE CHÂTELIER was born in Paris to Louis LE CHÂTELIER, an engineer trained at the Ecole Polytechnique and the Ecole des Mines who was responsible for building much of the French railway system. After attending the Collège Rollin in Paris, he entered the Ecole Polytechnique (1869) but shortly interrupted his study due to military service obligations during the Prussian siege of Paris (Dec. 1870 to Jan. 1871). He continued his education at the Ecole des Mines (1871) in order to be trained for the government engineering service. After graduation as a mining engineer (1873) and traveling in North Africa, he began his career in Besançon, northeastern France, as a mining engineer (1875) but soon decided dedicate his life full-time to teaching and research in chemistry. Already two years later he took up the chair of general chemistry at the Ecole des Mines in Paris (1877–1919). He also became instructor at the Ecole Polytechnique (1882) and later accepted the chair of mineral chemistry at the Collège de France (1887–1908).

When LE CHÂTELIER succeeded Ferdinand F.H. MOISSAN as professor of general chemistry at the Sorbonne, he entered the field of metallurgy and founded the journal *Revue de métallurgie* (1904). During World War I he worked for the Ministry of Armaments. Owing to a number of serious mine disasters in the 1870s in France, the Ecole des Mines was asked to investigate their cause and prevention as well (1878). Humphry DAVY had already shown that a certain temperature was needed to trigger explosions of firedamp in mines, but the propagation process of the flame was still unknown. Together with François Ernest MALLARD, a professor of metallurgy, he tackled this problem (1878–1883). They determined first the temperature of inflammation of various combustible mixtures, then measured photographically the velocity of propagation of a flame, and determined calorimetrically the specific heats of combustion up to the highest temperatures by using Robert W. BUNSEN's method of explosion in a closed vessel provided with a pressure gauge. In addition, they improved miner safety lamps and suggested to the mining industry the use of safer high explosives for mining applications.

LE CHÂTELIER developed an optical pyrometer and a platinum/rhodium thermocouple for measuring high temperatures. His early studies on the setting of cements composed of calcium silicates as well as on gases at high temperatures and later also on blast furnace reactions led to the study of chemical equilibrium and the conditions of reversible reactions. In 1888, he enunciated his *Loi de stabilité de l'équilibre chimique* (Law of Stability of Chemical Equilibrium), stating that if a system in a balanced state is disturbed, it will readjust in such a way as to tend to neutralize the disturbance and restore equilibrium – the so-called "Le Châtelier principle" (1888). His conclusion had been anticipated, independently and on a mathematical basis, in the late 1870s by the U.S. physicist J. Willard GIBBS.

He received the Davy Medal (1916) of the Royal Society of London. The Ecole des Mines still honors his memory

with the Le Châtelier Prize, which is awarded for the best doctoral thesis each year.

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LEMAITRE, Monseigneur Georges Henri-Joseph-Édouard (1894–1966)

▪ Belgian civil engineer, mathematician, cosmologist and priest; cofounder of Big Bang theory

Monseigneur Georges H.J.E. LEMAÎTRE was born in Charleroi (Hainaut province, Belgium) and educated at a Jesuit school. He entered the Catholic University at Louvain (Flem. *Leuven*) to study engineering (1911) but in 1914 joined the army. After World War I, he returned to Louvain University and obtained his doctorate in applied mathematics (1920), taking up also theological studies, which led to ordination with the clerical rank of Abbé (1923). Shortly thereafter, he visited the University of Cambridge (1923), where the British astrophysicist and cosmogonist Arthur EDDINGTON initiated him into modern stellar astronomy and numerical analysis. He spent the following year for postgraduate training in the United States in Cambridge, MA at Harvard College Observatory and MIT with the U.S. astronomer Harlow SHAPLEY, an expert on nebulae. After his return to Louvain (1925) he initially worked as a part-time lecturer and on his Ph.D. thesis, which was entitled *The Gravitational Field in a Fluid Sphere of Uniform Invariant Density According to the Theory of Relativity* (1927). In the same year, he was appointed full professor of astrophysics at Louvain University. He eventually became professor of applied mathematics and was elevated to the clerical rank of Canon and later to the rank of Monseigneur. During a period of 40 years of association with Louvain University, he devoted his talents to both research and teaching.

LEMAÎTRE's contributions to astrophysics essentially covered three fields: (1) the development of a relativistic model of the Universe, his most famous work; (2) research on cosmic rays; and (3) attempts to solve the three-body problem. Independently of the Russian scientist Alexander FRIEDMANN, he published in 1927 a model of an expanding Universe that stood in contrast to the static cosmological model previously developed by Albert EINSTEIN (1917). LEMAÎTRE explained the expansion of the Universe by the explosion of a highly condensed "primeval atom" [French *atome primitif*]

– later popularly known as the "Big Bang theory" – and used Edwin P. HUBBLE's dramatic discovery of reddening in the spectra of distant nebulae as evidence for his theory.

LEMAÎTRE also pondered the origin of cosmic rays, which he considered fossils of the enormous radioactive disintegration process that must have taken place during the initial phase of the Big Bang event. Based on Carl STÖRMER's theory of charged particles in magnetic fields, LEMAÎTRE and Manuel S. VALLARTA, a Mexican-born U.S. scientist at MIT, predicted an east-west asymmetry of cosmic rays – the so-called "Störmer-Lemaître-Vallarta theory" of the trajectories of primary cosmic rays. Measurements carried out in the early 1930s by Thomas H. JOHNSON, Luis W. ALVAREZ, and Arthur H. COMPTON finally proved the charged-particle nature of cosmic rays.

LEMAÎTRE won the Prix Francqui (1934) of the Francqui Foundation at Brussels University, the highest Belgian scientific distinction, and was awarded the first Eddington Medal (1953) by the Royal Astronomical Society. In 1941, he was elected member of the Royal Academy of Sciences and Arts of Belgium. From 1960 he was president of the Pontificial Academy of Sciences in Rome.

Since 1995, the *Georges Lemaître Prize*, instituted by the Belgian *Georges Lemaître Foundation*, is awarded at least once every 2 years to a Belgian or foreign author who has made a significant contribution to increasing scientific knowledge in the fields of cosmology, astronomy, astrophysics, geophysics, and space research.

A crater on the far side of the Moon is named for him.

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NOTE. The works of G. LEMAÎTRE and a complete list of his publications are kept at the Library of the Belgian Royal Academy in Brussels under No. 55252.

LÉMERY [or LEMERI], Nicolas (1645–1715)

▪ French chemist and pharmacist

Nicolas LÉMERY was born in Rouen (Dépt. Seine-Maritime) to Julien LÉMERY, a Protestant attorney in the parliament of Normandy. After serving 6 years as an apprentice in a pharmacy of his uncle in Rouen, he went to Paris (1666), Lyon, Geneva, and Montpellier (1668–1671), where he studied pharmacy and taught chemistry. Returning to Paris, he purchased the office of "Apothecary to the King," which provided a secure financial position. Facing increasing difficulties as a Protestant, he left France for about a year and went into exile in England (1683). Losing after his return his privi-

leged apothecary, he converted to Catholicism, which allowed him to reestablish his laboratory and shop. He became an associated chemist of the Academy of Sciences (1699) and continued working, teaching, and writing in various fields of chemistry and pharmacy.

His *Cours de chymie* (1675), a textbook on chemistry that passed through numerous editions, was translated into Latin and all the major European languages. Also, his *Traité universel des drogues simples* (1698), a dictionary of various medicaments and their therapeutic action, became widely known. His chief contribution to pharmacy were his two complementary works, the *Pharmacopée universelle* (1697) and the *Traité des drogues simples* (1698). He worked out various methods of preparing antimony of mineral antimony, which he described in his book *Traité de l'antimoine* (1707), his last major work. In addition, he contributed a number of papers to the French Academy.

LÉMERY also speculated on the origin of subterranean fires, earthquakes, hurricanes, thunder, and lightning and experimented with oxyhydrogen explosions. His explosion model experiment – developed into an apparatus for easy demonstration purposes and becoming widely known as the "Volcan de Lémery" (1700) – was based on a reaction between filings of iron and sulfurous acid. It was even cited by prominent 18th-century naturalists (such as Immanuel KANT) for explaining explosive volcanic eruptions and earthquakes, although it could not provide a plausible explanation, by him or by his followers, of how nature, prior to reaction, could have provided and kept separate such huge quantities of pure iron and sulfur in the Earth's interior. Although not mentioning LÉMERY by name, Denis DIDEROT and Jean LE ROND D'ALEMBERT also referred to this curious experiment in their *Encyclopédie* [vol. 17, p. 446 (1765)]. Apparently, the British chemist Humphry DAVY first questioned his volcano model to explain volcanic explosive eruptions by subterraneous oxyhydrogen explosions (1828).

Although LÉMERY did not develop any rigorous theory of chemical reactions, he presented many attractive chemical ideas and first introduced the distinction between *chimie minérale* (inorganic chemistry) and *chimie organique* (organic chemistry).

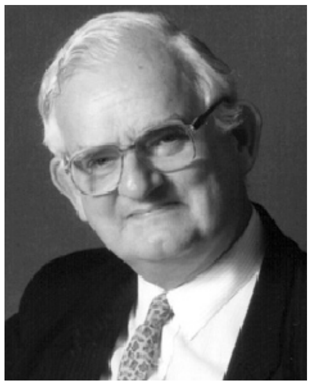
ORIGINAL WORKS. *Recueil des curiosités rares et nouvelles des plus admirables effets de la nature et de l'art.* P. Vander Aa, Leiden (1684) — *Chimique des feux souterrains, des tremblements de terre, des ouraganes, des éclairs et du tonnerre.* Mém. Acad. Paris (1700), pp. 140-152 — *Cours de chimie.* Chez l'auteur, Paris (1675) — *Dictionnaire, ou Traité universel des drogues simples…* J. Hofhout, Rotterdam (1727).

SECONDARY LITERATURE. P.A. CAP: *Nicolas LEMERY, chimiste né à Rouen le 19 Novembre 1645*. Fonderie de Fan, Paris (1839) — A.J.J. VANDEVELDE: *L'œuvre bibliographique de Nicolas LEMERY.* Bull. Soc. Chim. Belges **30**, 153-166 (1921) — O. HANNAWAY: *N. LÉMERY.* In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography.* Scribner, New York, vol. 8 (1973), pp. 171-175 — M. BOUGARD: *La chimie de Nicolas LÉMERY.* Turnhout, Brepols (1999).

PICTURE. Courtesy Deutsches Museum, Munich, Germany.

LIGHTHILL, Sir Michael James (1924–1998)

▪ French-born British applied mathematician and fluid dynamicist; founder of aeroacoustics and biofluiddynamics



Sir M. James LIGHTHILL was born in Paris to Earnest Balzar LIGHTHILL, a mining engineer who in 1917 changed the family name from LICHTENBERG to avoid anti-German sentiment. In 1927, his family left France. Growing up in England, he was first educated by his father. Later he won a scholarship to Winchester College (1936) and was awarded a major scholarship to Trinity College, Cambridge (1939), where he studied mathematics (1941–1943) and from which he graduated (B.A., 1943). He was sent to the Aerodynamics Division of the National Physical Laboratory (NPL) at Teddington (1943–1945), where he carried out research for the Aeronautical Research Committee (ARC) and first got involved in problems of supersonic flight. He also analytically studied aerodynamic drag of fine-pointed bodies of revolution and contributed to 2-D supersonic airfoil theory.

After World War II, Sir LIGHTHILL was awarded a prized fellowship at Trinity College and became senior lecturer in mathematics at the University of Manchester (1946–1950), where he was strongly influenced by Sir Geoffrey I. TAY-

LOR, an eminent British fluid dynamicist. At the University of Manchester he succeeded Sydney GOLDSTEIN in the Beyer chair of applied mathematics (1950–1959). In 1949, he extended the classical Poincaré method of nonlinear mechanics. This so-called "Poincaré-Lighthill-Kuo (PLK) technique" of strained coordinates for obtaning uniformly vald approximations for certain classes of ordinary and partial differential equations consists in perturbing not only the unknown, but also the independent variables. In the late 1940s, the Ministry of Aviation asked him to determine if jet aircraft, originally developed for military purposes, could also be used for civilian purposes, and how jets could be made quieter and more powerful at the same time. This resulted in his renowned paper on aeroacoustics in which he formulated his "Eighth Power Law of Jet Noise," stating that the radiated acoustic power for a jet engine is proportional to the eighth power of the jet exit velocity (1952).

Sir LIGHTHILL also worked extensively on gas dynamics at very high speeds, including ionization processes during reentry, and studied diffraction effects of shock and blast waves. His generalization of the hodograph method for flow past solid boundaries allowed nonlinear phenomena to be analyzed via linear equations (1953). His book *Surveys in Mechanics*, published in 1956 to celebrate Sir G.I. TAYLOR's 70th birthday, addressed the new subject of nonlinear acoustics. In the period 1950–1966, he treated important problems of boundary layers covering the range from subsonic to supersonic velocities, as well as in fluctuating streams. He also contributed to the theory of waves in the ocean and the atmosphere. For example, he worked out the differences between nonlinear acoustics and the propagation of waves in shallow water (*e.g.*, tidal bores) – a subject of great fascination that had already attracted many early shock pioneers. When studying how animals move through air or water, he created the new discipline of biofluiddynamics, which brought him renown beyond the physics community.

In the period 1959–1964, he was director of the Royal Aircraft Establishment (RAE) at Farnborough. His research contributed to the aerodynamics of dart-shaped supersonic aircraft (1962), leading eventually to the slender delta-wing design of the SST Concorde. In the 1960s, Sir LIGHTHILL also helped NASA on its high-speed civil transport (HSCT) project, in particular on how to minimize the level of supersonic noise. However, this project was phased out in 1999 due to economic constraints.

After holding a Royal Society research professorship (1964–1969) at Imperial College, London, he returned to Cambridge as Lucasian professor of mathematics (1969–1979). Thereafter, he took on a more administrative role as provost of University College, London (1979–1989). After his retirement in 1989 he traveled and lectured worldwide, acting as chair of the International Council of Scientific Union (ICSU) Special Committee for the International Decade for Natural Disaster Reduction (IDNR).

He was one of the founding associate editors of the *Journal of Fluid Mechanics* (1956). He also served as vice president (1965–1969) of the Royal Society and was president (1984–1988) of the International Union of Theoretical and Applied Mathematics (IUTAM). Sir LIGHTHILL, who held 24 honorary doctorates, was a member of many prestigious foreign academies and was knighted (1971). He was awarded the Royal Medal (1964) and the Copley Medal (1998) of the Royal Society of London, the Cresson Medal (1975) of the Benjamin Franklin Institute, the G.I. Taylor Medal (1984) of the Society of Engineering Science, the first Theodorsen Medal (1993) of NASA Langley, and many other awards.

He made innovative contributions to such fields as applied mathematics, aerodynamics, astrophysics, and fluid mechanics. He wrote 6 books and published about 150 papers. Today he is considered one of the greatest applied mathematicians of the 20th century. To get a comprehensive survey of his enormous output, the reader is referred to his *Collected Papers* (1997). He presented numerous keynotes to various congresses, his last one, given in 1997 at the 5th International Congress on Sound and Vibration in Adelaide, Australia, was entitled "A Century of Shock Wave Dynamics." One year later, he died at age 74 while attempting to swim around Sark Island, U.K.

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PICTURE. Courtesy Michael LIGHTHILL, son of Prof. LIGHTHILL, London, U.K.

MACH, Ernst Waldfried Joseph Wenzel (1838–1916)

▪ Austrian physicist, psychologist, and philosopher of science; father of supersonics

Ernst W.J.W. MACH was born in Chirlitz-Turas in Moravia (now Chrlice-Tuřany, Czech Republic), at that time part of the Austro-Hungarian Empire. His father Johann MACH had an excellent classical education and was a gymnasium professor, later acting also as private tutor. Up to the age of 15 he was mostly educated by his father. After finishing the gymnasium (1855) in Kremsier (now Kroměříž, Czech Republic) in South Moravia, he studied mathematics, physics, and philosophy at the University of Vienna, where he received his Ph.D. (1860) with a thesis entitled *Über die elektrische Entladung und Induktion* ("On the Electric Discharge and Induction"). He became *Privatdozent* (university lecturer) and worked in the laboratory of Prof. Andreas VON ETTINGSHAUSEN, Christian DOPPLER's successor as chair of experimental physics. One of his tasks was the experimental verification of the Doppler effect. For this purpose he built a special machine that allowed him to demonstrate that Joseph PETZVAL's hypothesis as well as that of DOPPLER (which were rival hypotheses) were in fact correct. In 1864, he became full professor of mathematics at the University of Graz, but in 1867 accepted a professorship of experimental physics at the German Karlsuniversität (Charles University) in Prague, which provided better resources for his experimental studies (1867–1895). As Rector Magnificus (1879–1880) he fought against the introduction of Czech instead of German at Prague University.

During the 28 years he spent in that chair MACH produced most of his important work and published all of his research in gas dynamics, ballistics, and high-speed instrumentation. In 1895, he became professor of philosophy at the University of Vienna, holding there the chair of history and theory of the inductive sciences. After suffering a stroke in 1897, which left the right side of his body paralyzed, he only partly recuperated and retired prematurely in 1901. In the same year, MACH was made a member of the Austrian House of

Peers. In 1913, at the age of 75, he moved to the country home of his son Ludwig in Vaterstetten, a small town in the southeast of Munich, where he died on February 19, 1916, one day after his 78th birthday. Most of his life MACH dedicated to the philosophy of science and to problems in physiology and psychology.

In his famous book *Die Mechanik in ihrer Entwicklung historisch-kritisch dargestellt* ("The Science of Mechanics: a Critical and Historical Account of its Development," 1883), he critically discusses Sir Isaac NEWTON's mechanical views and suggests the elimination of all proportions from which observables cannot be deduced. In his later book *Beiträge zur Analyse der Empfindungen* (1886, translated in 1897 as "Contributions to the Analysis of the Sensations"), which became a classic in the physiology and psychology of sensations, MACH elaborated a new scientific positivism, exerting a powerful influence on those searching for a formula by means of which psychology might be included among the natural sciences. He argued that any physical theory that refers to objects not reducible to sensory experiences must be rejected as metaphysical. All experimental data are neutral by themselves and should merely serve to derive scientific concepts, theories, or laws in order to obtain cognition. His positivistic criteria of verifiability led him to reject the introduction of (invisibly small) atoms and molecules into physical theory. However, his rigorous concept of *"Sehen heißt Verstehen"* ("Seeing is understanding") promoted insight into high-speed phenomena that cannot be resolved by the naked eye and rely heavily upon high-speed visualization and recording methods. This greatly stimulated new physical disciplines such as shock waves, detonics, and supersonic ballistics.

Ernst MACH, who had planned supersonic ballistic experiments several years before Prof. Peter SALCHER, an Austrian physicist at the Imperial Navy, eventually succeeded in photographing them (1886). MACH immediately gave a correct interpretation of the head wave and the lines emanating from projectile surfaces. These supersonic flow phenomena were later connected with his name, such as the *Mach angle, Mach cone, Mach head wave*, *Mach line*, and *Mach wave*. Furthermore, MACH also studied the oblique interaction of shock waves, thereby discovering irregular reflection (*Mach reflection effect*) and the origin of a new shock wave (*Mach disk*, *Mach front*, *Mach stem*), which since the 1940s has stimulated worldwide research activities to better understand this puzzling "Mach effect." He discovered *Mach bands*, an optical illusion which is also known as the "Mach effect" in the physiology community.

MACH's postulate that the local behavior of matter is influenced by the global properties of the Universe (1893) was resumed by Albert EINSTEIN and called by him "MACH's principle." EINSTEIN (1912) wrote, "the entire inertia of a point mass is the effect of the presence of all other masses, deriving from a kind of interaction with the latter … This is exact the point of view which Ernst MACH urged in his acute investigation on the subject."

In 1895, MACH moved with his wife to the country home of his son Ludwig in Vaterstetten, Bavaria, where he died on February 19, 1916 – one day after his 78th birthday. In his obituary EINSTEIN wrote in April 1916, "He succeeded in taking photographs of the density distribution of air in the environment of a projectile flying with supersonic speed and thus shed light on a genre of acoustic processes about which nothing was known before him." MACH's numerous pioneering discoveries in supersonics and aeroballistics were of immediate military importance and quickly brought him international fame. The Swiss aerodynamicist Jakob ACKERET (1929), honoring his contributions to gas dynamics, proposed naming the ratio of supersonic to sound velocity the "Mach number," which today is generally applied.

Since 1991 the *Ernst Mach Memorial Lecture* is presented at the International Symposium on Shock Waves by a distinguished scientist to commemorate MACH's contributions to supersonics and shock waves. Since 1995 the Academy of Sciences of the Czech Republic in Prague has presented the *Ernst Mach Honorary Medal* to recognize outstanding scientific results achieved in the field of physics (http://www.mpq.mpg.de/mpq-awards/mach-medal.html).

A crater on the far side of the Moon and a minor planet (asteroid 3949 MACH) are also named for him.

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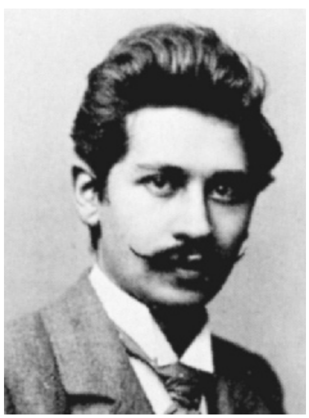
PICTURE. Archives of Ernst-Mach-Institut (EMI), Freiburg, Germany.

NOTE. Ernst MACH's scientific legacy comprises (1) his scientific notebooks; (2) a large collection of shock wave photos recorded on silver bromide gelatin dry plates, including the famous first photographs of high-speed projectiles and shock waves generated by electric spark discharges; (3) his correspondence with famous scientists such as BOLTZMANN, BOYS, DUHEM, DVORAK, EINSTEIN, FEDDERSEN, VON HELMHOLTZ, HERTZ, KELVIN, MELSENS, PLANCK, SALCHER, TOEPLER, *etc.*; (4) a collection of his awards and medals of honor; and (5) a part of his personal library. The major part of his legacy was donated in 1959 by Mrs. Karma MACH, Ludwig MACH's wife, to the Ernst-Mach-Institut (EMI), Freiburg. EMI's total collection was transferred in 1998 to the Deutsches Museum at Munich; 942 photographs taken by Ernst MACH and collaborators can now be seen in the Internet, *see* http://www.deutsches-museum.de\bib/archiv/mach/index.htm. A part of his personal library was purchased around 1960 from L. MACH's heirs by the Institut für Aerodynamik (IfA) of the ETH Zurich (priv. comm. by Prof. Herbert SPRENGER, IfA, ETHZ).

MACH, Ludwig (1868–1951)

▪ Austrian physician, physicist, and inventor



Ludwig MACH was born in Prague and was the eldest son of Ernst MACH, an eminent Austrian professor of natural philosophy. In 1887/1888, he began to study medicine at the German Charles University in Prague. Beginning in the late 1880s, however, he devoted more time to improving his father's laboratory equipment than to his own medical studies.

Ludwig MACH was a skillful experimenter. Together with his father he performed further important supersonic ballistic experiments and modified the Jamin interferometer that his father had used to obtain data on the strength of shock waves. The new instrument, put in operation in 1891, was called the "Mach-Zehnder interferometer," because its principle was invented independently in the same year by Ludwig ZEHNDER, a Ph.D. candidate of Prof. Wilhelm C. RÖNTGEN. This interferometer, which makes the distance between the measuring and reference light beams greater than in the Jamin interferometer, is very useful to visualize the density profiles in shock waves and ballistic head waves.

After his doctorate (*medicinae universae doctor*, July 1895) he did not enter medical practice but rather went to the Optischen Werke Zeiss at Jena. In 1896, Ludwig MACH was the first to introduce *particle tracer photogrammetry* into high-speed flow diagnostics: he photographed the flow of air in a wind tunnel using silk threads, cigarette smoke, and glowing particles of iron.

Because of serious health problems his father was forced to give up his chair at the University of Vienna in 1913 and moved to his son's country house outside of Munich in Vaterstetten in an isolated forest. Here Ludwig MACH assisted his father in finishing his publications, planned together with him experiments on the speed of light to discourage relativistic speculations, and promised him to complete and publish his remaining manuscripts, including also part II of *The Principles of Physical Optics*. However, his father specified that in case of a failure of the light experiments, this manuscript should be destroyed.

After his father's death (1916), he began to publish manuscripts from his father under his supervision and changed from a supporter to an opponent of Albert EINSTEIN's ideas of relativity. In the 1933 edition of his father's monograph *Science of Mechanics*, he removed the pro-Einstein afterword of his father and inserted his own anti-Einstein foreword, which brought him into controversy with some contemporaries. Since his light experiments could not be completed in Vaterstetten due to various circumstances, he destroyed all the remaining unpublished manuscripts of his father.

Ludwig MACH had dedicated himself to aiding his father in any and every possible manner. Frustrated in his efforts at the end of his life, he described himself as someone who "fought for a dead man whose shadow I always was" [Germ. *"Ich kämpfte für einen Toten, dessen Schatten ich immer war."*].

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PICTURE. Archives of Ernst-Mach-Institut, Freiburg, Germany.

MAIYEVSKY [Russ. *МАИЕВСКИЙ* or *МАЙЕВСКИЙ*], Nikolai Vladimirovich (1823–1892)

▪ Russian physicist and ballistician

Nikolai V. MAIYEVSKY was born in the country seat of his parents' home at Pervino near Torzhok, administrative district of Tver. After studying physics and mathematics at the University of Moscow and taking his Ph.D. (1839–1843), he obtained his officer's training at the artillery school of Mikhailovskoe. Serving first in a mounted artillery brigade (1846–1850), General E.C. VESSEL called on him in the Artillery Division of the Military Academy Commission. Quickly

working successfully in the field of exterior ballistics under Aleksei Vasplevich DYADIN, a general lieutenant of the artillery and a renowned Russian ballistician, he was appointed member of the commission and professor of the military academy.

His ballistic courses, which were based upon the results of his latest scientific studies but also matched practical needs, were internationally acknowledged and recorded in his two textbooks, which are entitled, in translation, *Courses on Exterior Ballistics* (1870) and *The Method of the Smallest Squares, Particularly Its Application to the Analysis of Ballistic Data* (1881), the latter introducing the theory of probabilities into practical training on artillery guns.

In exterior ballistics he investigated aeroballistic drag of spherical projectiles up to $M = 2$, thereby recognizing that the ratio of projectile velocity to sound velocity – later termed the *Mach number* – is an important parameter governing aerodynamic drag at high speeds. In the early 1860s, he studied ballistic problems arising from shooting long projectiles up to $M = 2$ from rifled barrels, such as the influence of rotation along the trajectory. Shortly after publication, this subject was resumed by the Irish engineer Robert MALLET, who proved that no rifled bullet could take anything but a curved course through tissues of the human body, an important finding for military surgeons. MAIYEVSKY also corrected existing firing tables. In interior ballistics he contributed to the design of durable and efficient gun barrels, collaborating in their fabrication with the German Krupp-Werke at Essen. He measured the pressure of explosion gases in gun barrels and, studying the choice of appropriate gunpowders for large guns, proved the superiority of prismatic powders.

MAIYEVSKY's memoir on impact phenomena of rotating projectiles, which was also translated into French, earned him wide acclaim as an international expert on ballistics and the Great Order of Mikhailovskoe (1866). In recognition of his scientific achievements the University of Moscow honored him with a doctorate in applied mathematics (1870). He was a corresponding member of the Academy of Sciences (since 1878) and an honorary member of the University of Moscow (from 1890).

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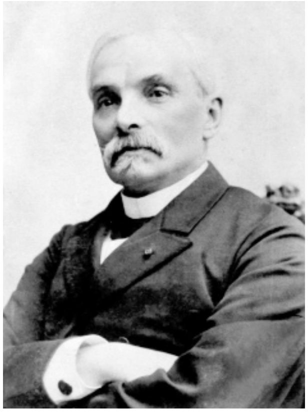
PICTURE. From *Russian men of science.* Nauka, Moscow (1965), vol. I, p. 170.

NOTE. His name has also been transliterated as MAIEVSKIJ.

MALLARD, François Ernest (1833–1894)

▪ French mineralogist, metallurgist and mining engineer

F. Ernest MALLARD was born in Châteauneuf-sur-Cher (Dépt. Cher). His father was a lawyer. After studying at the Collège de Bourges, the Ecole Polytechnique, and the Ecole des Mines in Paris, he graduated as Engineer of Mines (1853). Beginning as a geologist at the Corps des Mines, he was nominated professor of geology, mineralogy, and physics at the Ecole des Mines in Saint-Etienne (1859). His studies in crystallography began when he was chosen to fill the



vacant chair of mineralogy at the Ecole des Mines at Paris (1872), where he stayed until his death. He became Inspecteur Général des Mines (1886), was elected the second president of the Mineralogical Society of France, and was a member of the French Academy of Sciences (1890). He received the Croix de chevalier (1869) and became an officer of the Légion d'Honneur (1888). The University of Bordeaux awarded him an honorary doctorate (1888).

MALLARD's scientific studies as a mining engineer began in Saint-Etienne (Dépt. Loire) on studying the use of the safety lamp in coal mines (1868). He uncovered the dangers arising by the use of the Davy lamp and proposed various improvements. Ten years later, he became a member of the Commission du grisou, the French Firedamp Commission that was established to prevent methane explosions in mines.

In a very fruitful cooperation with Henry L. LE CHÂTELIER, then professor of general chemistry at the Ecole des Mines, he started a thorough investigation into the ignition temperature of gaseous explosions the results of which had a significant impact on practical mining. In addition, his studies on the specific heat and dissociation temperatures were of great scientific value for the understanding of explosion processes. Their joint studies revealed the importance of mixtures of coal dust and instituted the use of ammonium nitrate as a "safe explosive" in the mining industry. Its detonation temperature amounts to only 1,100 °C, which is low compared to about 2,500 °C for common explosives. Ammonium nitrate is the preferred explosive for shooting purposes to this day.

To the physics community MALLARD is probably better known for his contributions to crystallography and for his classic two-volume textbook *Traité de Cristallographie géométrique et physique* ("Treatise on Geometric and Physical Crystallography," 1879, 1884) rather than for his explosion studies. Stimulated by Auguste BRAVAIS' book *Etudes cristallographiques* ("Crystallographic Studies," 1866), he applied this theory to an understanding of the wide range of physical properties of crystals. From 1879 he published memoirs on optical anomalies, on the quasi-cubic form of all crystallized bodies, on the transformations of the polymorphous substances, and on isomorphous mixtures. He also refined the Wollaston goniometer, which resulted in his so-called "Mallard goniometer." It allows the precise measurement of the angles of crystallographic axes and indexes of refraction in glasses and crystals.

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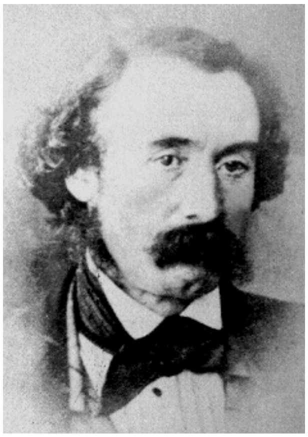
LAPPARENT: *Notice nécrologique sur Ernest MALLARD. Membre de l'Institut, inspecteur général des mines* [with a list of his publications]. Ann Mines **7** [IX], 267-303 (1895); *MALLARD.* In: *Livre du centenaire 1794–1894*. Tome 1: *L'Ecole et la science.* Gauthier-Villars, Paris (1895) — P. TERNIER: *Eloge d'Ernest MALLARD.* Bull. Soc. Géol. France **23** [III], 179-191 (1895) — W.T. HOLSER: *MALLARD, (François) Ernest.* In: (C.C. GILLESPIE, ed.) *Dictionary of scientific biography.* Scribner, New York; vol. 9 (1974), pp. 58-60 — Anonymous: *E.F. MALLARD* [biographie et son goniomètre]. In: (M.C. THOORIS ET AL., eds.) *Les objets scientifiques: un siècle d'enseignement et de recherche à l'Ecole polytechnique.* Ecole Polytechnique, Palaiseau (Sept. 1997).

PICTURE. Courtesy Bibliothèque de l'Ecole des Mines, Paris, France.

MALLET, Robert (1810–1881)

▪ Irish civil engineer and seismologist; father of seismology



Robert MALLET was born in Dublin to John MALLET, an iron founder. He entered Trinity College at Dublin (1826), where he studied mathematics and science, graduating with a B.A. (1830). In the following year, he became partner in his father's works, an iron and copper foundry in the city of Dublin that ultimately became the largest works in Ireland.

His contributions to civil engineering are manifold: in 1837, he turned his attention to the hydraulic ram and produced a form of that pump that was used on the Dublin and Kingstown railway for forcing water to tanks for the engines. He built a number of swivel bridges over the River Shannon and the viaduct over the Nore, erected many terminal railway stations, built the famous Fastnet Rock lighthouse (southwest of Cape Clear, Ireland) in the period 1848–1849, and obtained a number of patents. In 1850, MALLET, among others, sought means of reinforcing the wrought-iron gun tube such as by winding sheet iron around the tube or using hoops shrunk together. He invented the buckled plate, which was used widely in structures, particularly for flooring, where it combined maximum strength with minimum depth and weight (patented in 1852).

In 1861, he gave up his father's Victoria foundry, which he had expanded into the dominant foundry in Ireland, and took the M.A. (1862) at the University of Dublin. Two years later he received a honorary LL.D. from Dublin University.

As early as the mid-1830s MALLET started his studies in physical geology, which were directed toward four main areas: glacial flowage (1837–1845), geological dynamics (from 1835), seismology (from 1845), and volcanology (from 1862). In 1846, he delivered before the Royal Irish Academy a remarkable paper on the *Dynamics of Earthquakes*, thereby addressing the vertical motion believed or supposed to accompany earthquake shocks. He was also one of the first to estimate the depth of an earthquake underground and, based upon his conclusions on the origin of earthquakes, he can be regarded as an important precursor of plate tectonics.

It was the commencement of a long series of contributions to a branch of physical geology that he called "seismology" and with which his name is associated until now. His classic paper is today regarded as one of the foundations of modern seismology. Other contributions to this subject included (1) the *Catalogue of the World's Earthquakes* (1852–1854), which he jointly compiled with his son John W. MALLET and forms his third report on earthquake phenomena and occupies nearly 600 pages in the Reports of the British Association; (2) the two-volume book *The Great Neapolitan Earthquake of 1857* (1862); (3) the *Seismographic Map of the World* (1857) published by the British Association; (4) the article *First Principles of Observational Seismology* (1862), an extension of his first article *Earthquake Phenomena* (1847) published as a three-part memoir (1850–1852); and (5) an elaborate contribution to the literature of volcanic geology, entitled *Volcanic Energy* (1872).

MALLET's idea was to look for variations in seismic velocity that would indicate variations in the properties of the earth. Using gunpowder he carried out the first seismic measurements of the velocity of earth waves. The first tests using this new method began in the wet sand of Killiney Bay and the granite of Dalkey Island (1851) and later during the progress of extensive quarrying for materials for the construction of Holyhead Harbor, North Wales, in different lengths of quartz rock, slate, and schist, thereby using for the first time the enormous blast from a large quantity of fired gunpowder – thus introducing *explosion seismology* into geological research (1860). His method is still used today, for example in oil field exploration.

MALLET was also the first to investigate the physical conditions involved in the construction of large guns, particularly of ringed ordnance. In view of the Crimean War

(1854) he designed two monster mortars for throwing 36-in. (91.44-cm) shells, but they were ultimately not used owing to the peace agreement with Russia of 1856. MALLET delivered before the Royal Irish Academy a paper on the construction of large-caliber guns and hitherto unexplained causes of destruction (1856). He also published a paper in which he analytically treated the trajectory of a rifled projectile, either flat-faced or ogival-pointed, when it travels through air or penetrates a homogeneous denser or solid-resisting medium such as sand (1867). He found that in oblique fire the ogival-pointed shot must pass at an angle significantly less than that of incidence. In consequence of his contributions to ballistics he was later elected a special honorary member of the Royal Artillery Institution, Woolwich, south-east London (1867).

When MALLET gave up his ironworks at Dublin (1861), he moved to London, where he served as a consulting engineer. MALLET was also general editor of the *Practical Mechanic's Journal* (London). As a contribution to Prof. Luigi PALMIERI's book *The Eruption of Vesuvius in 1872* (1873), MALLET wrote an introductory sketch of the present state of knowledge of terrestrial volcanicity and the cosmic nature and relations of volcanoes and earthquakes. He also urged the establishment of an international chain of seismological observatories to study the velocity of earthquake waves and to use this information to elucidate the structure of the ocean floors about which very little was then known.

In the last seven years of his life he was nearly blind, and his papers were written by the hand of an amanuensis. MALLET was a member of the Royal Irish Academy (1832), elected an honorary member of the Society of Scotland (1840), a Fellow of the Royal Society (1854) and the Geological Society of London (1859), and a corresponding member of the Physical Class of the Royal Philosophical Society of Göttingen (1869). MALLET received the Telford Medal of the Institution of Civil Engineers (1859) and the Cunningham Medal (1862) of the Royal Irish Academy. In 1877, he received the Wollaston Medal, the premier award of the Geological Society of London, "in recognition of the results of at least forty years of sedulous labor in some of the most important and difficult problems in geology."

Similar to MALLET, John MILNE, forty years younger than MALLET, made also fundamental contributions to seismology and earthquake engineering. The prestigious biennial *Mallet-Milne Lecture* is sponsored by the Society for Earthquake and Civil Engineering Dynamics (SECED) in London.

Astronomers named a crater on the near side of the Moon after him.

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PICTURE. Taken in 1865. Courtesy Grace FITZGERALD, The Institution of Engineers in Ireland, Dublin.

MARCI VON KRONLAND, Johann [Ioannes] Marcus (1595–1667)

▪ Bohemian physician (the "Bohemian Plato"), physicist and mathematician; early pioneer of percussion mechanics

J. Marcus MARCI VON KRONLAND was born in Landskron, Bohemia (now Lanškroun, Czech Republic), the son of a clerk to an aristocrat. He received his basic education in a Jesuit college. He studied philosophy and theology at the University of Olomouc (now in the Czech Republic) with the intention of becoming a priest. However, for some reason he changed his mind and in 1618 commenced his studies in medicine at Karlsuniversität (German Charles University) in Prague, then a significant center of early natural sciences. There he took his M.D. (1625) and, beginning in the same year as a lecturer, soon became professor of medicine, a position he held for 40 years. His reputation as a very successful physician must have been legendary because contemporaries called him the "Hippocrates of Prague." He became physician in ordinary to Emperor Ferdinand III (1658). Besides his interest in philosophy – a kind of Platonism pointing in the direction of Johan B. VAN HELMONT and Philippus A. PARACELSUS, which earned him the nickname "Bohemian Plato" – he showed a keen interest in oriental languages and natural sciences, particularly in physics and mathematics.

It is not quite clear who stimulated and influenced his interest in tackling the problem of percussion. When MARCI published his book *De proportione motus*... ("Of Proportion in Motion…," 1639) on this subject, Galileo GALILEI (1564–1642) had published a year before his *Discorsi e Dimostrazioni Matematiche* – a treatise on mechanics, in addition to free fall and projectile motion, also including percussion (*see* his "Sixth Day"), which MARCI might have known before he published his own book on percussion. GALILEI's treatise, however, smuggled out of Italy and printed in Leiden in 1638 under the title *Discorsi e dimostrazioni matematiche intorno a due nuove scienze* ("Discourses and Mathematical Demonstrations Relating to Two New Sciences"), does not contain the passage on percussion. MARCI's contribution to the laws of percussion (or impact), although of qualitative rather than of quantitative nature, appears to be based on his own studies and experiments. He classified collisions into those between hard, soft, and fragile bodies. Recognizing the dependence of impulse on mass, he attempted to characterize impulse, which he regarded as a resistance to motion, in terms of static weight. Although this approach could not render successful results in mathematical terms because weight and impulse have different dimensions, he arrived by experiments at numerous correct conclusions. His significant results on collision phenomena, today almost forgotten, put him in first place in a line of early pioneers investigating the phenomena of percussion, which shortly afterward were taken up by renowned researchers, such as René DESCARTES, Christiaan HUYGENS, John WALLIS, and Christopher WREN.

Besides percussion, MARCI was also interested in other branches of mechanics, such as the free fall and the oscillation of a pendulum. The pendulum was used by early naturalists as a simple device for measuring an elapsed period of time. For example, the pendulum was used by GALILEI to take the pulse of a patient and by Marin MERSENNE to estimate the velocity of projectiles in relation to the sound velocity in air (1644). MARCI proposed a small pendulum for the measurement of time durations below one second (*De proportione motus*, Propositio XXXXI, Problema II).

MARCI published his optical studies in his monograph *Thaumantias. Liber de arcu coelesti*... ("The Rainbow…, 1648), in which he tried to explain the puzzle of the rainbow, his chief interest as indicated by the title of his work. He experimented with prisms to decompose white light and observed that each color corresponds to a specific refraction angle, thus anticipating several of Sir NEWTON's prismatic discoveries. To explain the change in direction in the reflection and refraction of light, he assumed that each point of a luminous source emitted rectangular rays in all directions, in a homogeneous medium bounded by a sphere, and that the points of this surface become the centers of new spheres of propagation, thus anticipating the Huygens principle.

MARCI was knighted for his achievements (1654) and granted the title Count Palatine de Kronland. Shortly after

entering the Jesuit Order, he died in Prague. He was one of the great scientists of the 17th century. Since 1977, the *I.M. Marci of Kronland Medal* for outstanding achievements in the field of spectroscopy is awarded annually by the Czech Spectroscopic Society of the Czech Academy of Sciences.

A crater on the far side of the Moon is named for him.

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PICTURE. From M. MARCI: *De proportione motus* (*see above*).

MARIOTTE [Lat. *MARIOTTUS*], Edmé (*c.*1620–1684)

▪ French physicist and plant physiologist; early pioneer of percussion mechanics and father of French hydraulics

Little is known with certainty of Edmé MARIOTTE's biography, such as the origin of his family, the place of his birth, his motivation to devote himself to science, his education and career before entering the French Royal Academy of Sciences, and even of his private life as an Academician.

He was born around 1620 in Dijon (Dépt. Côte d'Or) and entered the academy in 1666, some months after its official foundation. Some modern biographers state that he also served as a prior to St. Martin-sous-Beaune, but contemporary sources do not attribute to him a clerical title. All of his 9 published treatises and about 20 unpublished papers he prepared during his active period as an Academician. MARIOTTE began his scientific studies with physiological research on the vegetation of plants (delivered 1667) and the mechanism of seeing in the human eye (delivered 1668), thereby discovering the blind spot. After briefly treating an engineering problem, an improvement in the accuracy of a level instrument (1672), he soon turned to physics. His most important contribution are as follows: (1) He treated elastic and inelastic collisions of solid bodies and their deformation during impact (read 1671, publ. 1673, 1676, and 1684). His treatise soon became a standard work on collision phenomena. (2) His studies on the nature of air under isothermal conditions (1679), carried out independently of Robert BOYLE's previous findings, essentially confirmed the relationship $pV = \text{const}$ – so-called "isothermal gas law" or "Boyle law" (1660), later also known as the "Boyle-Mariotte law" which describes the isothermal behavior of an enclosed mass of air – a basic tenet of physics and chemistry. MARIOTTE even went further than BOYLE by stating that this relation only holds if there is no change in temperature. Therefore, in France his law is called the "Mariotte law." (3) He first applied his observed volume-pressure dependency to the Earth's atmosphere and showed that the pressure decreases with altitude. Coining the word "barometer," he also discussed the relation between barometric pressure and weather. (4) His investigation on the freezing of liquids (1672) showed that ice has a smaller density than water. (5) In his reports to the Paris Academy he discussed the rainbow, the refraction of light, and the nature of colors (1681). (6) In his studies on the movement of fluids (publ. posthumously in 1686), which deal with the basic properties of air and water, the balance forces of fluids due to weight, and elasticity and impact, he stated that water is practically incompressible and hence has no elastic force. (7) The first volume of the *Histoire et Mémoires de l'Académie* (1733) also contains a paper on the recoil of guns. (8) He also con-

ducted tests on the deformation and burst pressure of cylindrical vessels hold under high pressure of water. He observed that the vessels burst when the circumferential elongation increased by a certain fraction and noted the direct proportionality between pressure and circumferential stretch. His work, published posthumously in his book *Traité du mouvement des eaux et des autres corps fluides* (1686), marked one of the first efforts to relate strength to strain (or stress).

MARIOTTE corresponded with a number of eminent scientists of his time such as Philippe DE LA HIRE, Christiaan HUYGENS and Gottfried W. LEIBNIZ. His reputation was very high not only among French colleagues but also in England. In the second edition of his *Philosophia naturais principia mathematica* (1713), Sir Isaac NEWTON acknowledged MARIOTTE's pendulum experiments as an important contributions to the laws of impact, calling him "the most illustrious MARIOTTE" [Lat. *"Clarissimus Mariottus"*]. NEWTON was the most prominent user of his two-pendulum percussion apparatus, which he applied to verify the equivalence of action and reaction, later known as "NEWTON's Third Law of Motion" {Sir NEWTON ⇨1687}.

A crater on the far side of the Moon is also named for him.

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http://galileo.rice.edu/Catalog/NewFiles/mariotte.html.

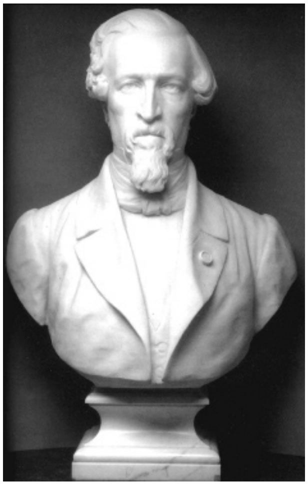
PICTURE. Courtesy Bildarchiv Preußischer Kulturbesitz (bpk), Berlin (image No. 51.295).

NOTE. There exists no official portrait of MARIOTTE. However, there exists a painting made by the French artist Charles LE BRUN on the occasion of the establishment of the French Academy and the foundation of the Paris Observatory on Dec. 22, 1666. This painting which is kept at the Musée National du Château et des Trianons in Versailles shows king Louis XIV, J.B. COLBERT and the 21 founding members, MARIOTTE being one of them. The enclosed picture is a detail of this painting, probably showing (from right to left) E. MARIOTTE, C. HUYGENS, and J.D. CASSINI. For further information *see* C.J. VERDUIN: *A portrait of Christiaan HUYGENS? in Etablissement de l'Académie des Sciences et fondation de l'Observatoire. 1666.* University of Leiden, The Netherlands;
http://www.leidenuniv.nl/fsw/verduin/stathist/huygens/acad1666/index.html.

MELSENS, Louis Henri Frédéric (1814–1886)

▪ Belgian chemist, physicist, and physician; founder of wound ballistics

Louis H.F. MELSENS was born in Louvain (Flem. *Leuven*) in the Province of Brabant. After attending a local gymnasium in his native town, he first worked in the office of a business at Anvers, where he discovered "his incapability for commercial life." He studied organic chemistry in Paris, working in the laboratory of Jean B.A. DUMAS at the Sorbonne. To increase his knowledge of chemistry he visited Germany and came into contact with Justus VON LIEBIG at the University of Giessen, an international authority on chemistry, where he took his Ph.D. in the natural sciences. After his return to Belgium MELSENS was appointed professor of chemistry and physics at the Ecole de Médecine Vétérinaire in Brussels. Later in Brussels he became an examiner at the Ecole Royale Militaire and a regular member of the Belgian Royal Academy of Sciences (1851).



Besides his numerous contributions to chemistry (*e.g.*, hydrous saponification of fats, determination of the empiric formula of nicotine) and pharmacy (*e.g.*, treatment of lead and mercury poisonings), he applied Benjamin FRANKLIN's principle that "all electricity goes up to the free surface of the bodies without diffusing in their interior substance" (the principle of the Faraday cage) to lightning conductors. The invention of the "Melsens lightning-conductor system" perfected the lightning rod: he multiplied the terminals, the conductors, and the earth-connections, which assumed the form of an aigrette or brush with five or seven points, the central point being a little higher than the rest.

He also performed ballistic experiments, thereby studying various kinds of impact phenomena that we would classify today as terminal ballistics. He also extended this research on living tissue and investigated gunshot wounds of humans and horses, today called "wound ballistics." In 1872, MELSENS speculated that the disrupting effect during impact of a projectile is caused by compressed air that is carried along with the projectile. His hypothesis, which was only based on the analysis of target fragments and not on any high-speed visualization and recording techniques during impact, was vague. In a lecture given in 1881, MELSENS presented his theory and stimulated Ernst MACH to investigate this challenging problem in more detail, which eventually resulted in the discovery of the head wave (1886) surrounding any object flying in a fluid at supersonic velocity.

MELSENS was the first president of the Belgian Electrotechnical Committee. The *Louis Melsens Prize*, created by the Division of Sciences of the Académie Royale de Belgique in 1900, is awarded to a Belgian or naturalized Belgian author of the most outstanding work, in a given year, on "applied chemistry or physics."

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PICTURE. Courtesy L'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique, Bruxelles, Belgium.

MERSENNE [Lat. *MERSENIUS*], Marin (1588–1648)

▪ French natural philosopher, mathematician, and theologian; promoter of French science

The son of a laborer, Marin MERSENNE was born near Oizé (Dépt. Maine), France, and began his grammar studies at the College of Mans in Paris. After spending 5 years at the new Jesuit College of La Flèche in Anjou (1604–1609) he studied theology at the Sorbonne (1609–1611). Thereafter he joined the Roman-Catholic mendicant Order of Minims (1611) and entered the Minim Convent de L'Annonciade in Paris. He temporarily taught philosophy at the Minim convents at Nevers and Paris, and beginning in 1620 he traveled extensively throughout western Europe.

MERSENNE, an opponent of any mystical doctrines of alchemy, astrology, and related arcane arts, tried to approach nature by scientific methods. He devoted himself to research in mathematics, physics, and astronomy rather than adopting speculations from others. His cell became a meeting place for a number of eminent natural philosophers throughout Europe, such as Girard DESARGUES, René DESCARTES, Pierre DE FERMAT, Blaise PASCAL, Pierre GASSENDI, Gilles Personne DE ROBERVAL, Jean BEAUGRAND, and others who later formed the core of the *Academia Parisiensis* (Parisian Academy of Sciences), which he organized in 1635. Corresponding with other eminent scientists in Europe such as Galileo GALILEI, Isaac BEECKMAN, Jan Baptista VAN HELMONT, Thomas HOBBES, Christiaan HUYGENS, Nicolas-Claude Fabri DE PEIRESC, and Evangelista TORRICELLI, he played a major role in communicating knowledge and ideas throughout European mathematical circles at a time when there were not yet special scientific periodicals. (For example, the first volume of the famous journal *Philosophical Transactions of the Royal Society* was not published until 1666). It was said that "To inform MERSENNE of a discovery, meant to publish it throughout the whole of Europe." He also defended DESCARTES and GALILEI against theological criticism.

In 1634, MERSENNE translated parts of GALILEI's *Dialogo sopra i due massimi sistemi del mondo* ("Dialogue Concerning the Two Chief Systems of the World," 1632) and in 1639 his *Discorsi e dimostrazioni matematiche intorno a due nuove scienze* ("Discourses and Mathematical Demonstrations Concerning the Two New Sciences," 1638) into French. Like his friend DESCARTES, he tried to explain that the world is based on a universal mechanism and that the actions of nature are limited by quantitative laws (*Harmonie universelle*, 1636). According to his understanding of science, the scholar has at his disposal three means: (1) the use of experiments; (2) the light of reason; and (3) the use of physico-mathematical processes together with the analogies in one field of physics with another. Physics – or any other natural science – is simply the science of phenomena, where experiments substitute for syllogistic argumentation and mathematical formulation takes the place of philosophical principles.

MERSENNE, however, was not only interested in natural philosophy on a general level but contributed also to specific fields, such as mathematics and experimental physics. In mathematics, MERSENNE worked on the theory of numbers. Investigating prime numbers, he tried to find a formula that would represent all primes and wrote a synopsis of mathematics that was printed in 1664. His other fields of study were mechanics, acoustics, hydrostatics, hydraulics, and ballistics. Probably stimulated by GALILEI's pendulum experiments, he first used a pendulum to measure gravity and suggested to the Dutch physicist Christiaan HUYGENS the use of the pendulum as a timing device. He also proposed a hygrometer and a telescope with parabolic mirrors.

Today MERSENNE is mostly known for his acoustic studies. He worked out a theory of music, studied the sound generated by pipes and strings, and performed the first measurements of the speed of sound in air (1636), which later inspired his closest friend GASSENDI to resume his studies. MERSENNE also showed that the velocity of sound is independent of pitch and loudness, and that the intensity of sound, like that of light, is inversely proportional to the distance from its source. When performing ballistic studies, he noticed that the impact of a musket ball against a wall is heard by a person, stationed on the far side and close to the point of impact, at the same instant as the report of the gun. From this observation he drew the important conclusion that the velocity of a musket ball must be of the same order as the velocity of sound. Obviously, he was the first to make a correct estimation of ballistic velocities that had hitherto been based solely on crude guesses without experimental support.

A crater (*Crater Mersenius*) on the far side of the Moon and some long, narrow valleys (*Rimae Mersenius*) on its surface are named after him.

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PICTURE. Copper engraving by Claude DUFLOS, early 17th century, Musée National des Châteaux de Versailles et de Trianon. Courtesy Gérard BLOT, Réunion des Musées Nationaux (RMN), Paris, France.

MIKHEL'SON [Russ. *МИХЕЛЬСОН*], Vladimir Aleksandrovich (1860–1927)

▪ Russian physicist and combustion researcher

Vladimir A. MIKHEL'SON was born in Tul'chin (now Vinnitsa Oblast, Ukraine) to Alexander Mikhaelovich MIKHEL'SON. After his education and graduation at M.V. Lomonosov Moscow State University (1883) he worked as a secretary of the Physics Section of the Society of Amateur Naturalists (1884–1887). Beginning in 1887 as an associate professor at Moscow State University [МГУ], he established the basic law governing the relationship between the composition of a burning gas mixture and the motion of the combustion front (1890–1893), thus laying the foundations of the theory of explosive combustion six years prior to the British chemist David L. CHAPMAN. Prior to Lord RAYLEIGH he derived an expression of the conservation of mass and momentum across the detonation front which corresponds to the straight Rayleigh line in the (p, v)-diagram – later known as the "Mikhel'son line." With these investigations he took his Ph.D. in physics (1893).

In 1894, he became professor of physics and meteorology in Moscow at the Petrov-Razumovsky Agricultural Academy (now Timiryazev Agricultural Academy), a position he held until his death. He also calculated the Doppler shift of light passing through a medium with a varying refraction index, directed an observatory of the U.S.S.R. Academy of Sciences, and later did research on actinometry and meteorology. Together with Nikolai E. ZHUKOVSKY he can be regarded as the most prominent 19th-century Russian shock and detonation physicist.

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PICTURE. From *Russian men of science.* Nauka, Moscow (1961), vol. I, p. 223.

NOTE. His name has also been transliterated as MICHELSEN and MICHEL'SON.

MINTROP, Ludger (1880–1956)

▪ German geophysicist and seismologist; father of seismic refraction method of exploration

Ludger MINTROP was born the son of a farmer at Werden/Heidhausen, a village near Essen, capital of the Ruhr

district. After attending the Rektoratsschule in Werden and the Realgymnasium in Essen, he studied surveying at the Berliner Bergakademie (1902–1903) and the TH Aachen (1903–1905). In addition, he worked as an assistant to Prof. Karl HAUSSMANN, a renowned geophysicist, at the Lehrstuhl für Markscheidekunde (Chair of Surveying) of TH Aachen, besides serving as consultant to the Nordstern Colliery. In 1907, he went to the University of Göttingen and joined the staff at the newly established Institut für Geophysik, which was founded and headed by the famous geophysicist Prof. Emil WIECHERT, then already widely known for his experiments on artificial earthquakes and his invention of the seismograph. MINTROP studied the seismic waves resulting from the concussive force of a falling body – the so-called "Mintrop ball," a 4,000-kg iron ball – which was dropped from a 14-m-high tower. With his first portable highly sensitive seismographs he obtained records that clearly showed the P- and S-waves. In 1908, he was called by the Westfälische Berggewerkschaftskasse and became a professor of surveying at the Bergschule Bochum and director of the surveying division and the newly established earthquake and geomagnetic observatory (1909–1921). He took his Ph.D. (1911) at Göttingen University with a thesis on the propagation of ground motions produced by a large gas turbine that had been installed at the Göttingen electric power station.

During World War I he developed a seismic method to locate Allied artillery firing positions using his portable seismograph. After the war he reversed the process, and by measuring the distance from an explosion to the seismograph he found that he could estimate subsurface geological formations. He discovered the *seismic head wave* – also known as the "Mintrop wave" – a wave that travels along the interface of two media having different velocities. With his patented *Seismic Exploration Refraction Method* (1919) he could estimate subsurface formations such as the existence of salt domes in Texas where oil was found (1923–1925). In 1921, MINTROP established the Seismos GmbH in Hannover, the first geophysical company using artificial earthquakes caused by the detonation of small charges of dynamite in a shallow bore hole for the exploration of valuable oil, coal, and ore deposits. At Seismos he held a leading position until 1933. He accepted a call to teach surveying and geophysics at the University of Breslau (1928–1945). After World War II, he escaped to western Germany, where he received at the TH Aachen a professorship in surveying and geophysics.

MINTROP, one of the "Grand Old Men" of geophysics, was a founding member of the German Seismological Society (1922), an honorary member of the Deutscher Markscheider Verein (German Surveying Association), the Society of Exploration Geophysicists (1930), and the Deutsche Geophysikalische Gesellschaft (German Geophysical Society) (1950). He received the Karl-Engler Medal (1953) and the Grand Cross of the Order of Merit of the Federal Republic of Germany (1955).

Since 1980 the annual *Mintrop Seminar,* organized by the Institut für Geophysik of the Ruhr University Bochum (RUB), is dedicated to special topics of applied geophysics, particularly to seismology. The *Ludger Mintrop Award* is annually presented to the author(s) of the best paper published in the international journal *Near Surface Geophysics* (Tulsa, OK).

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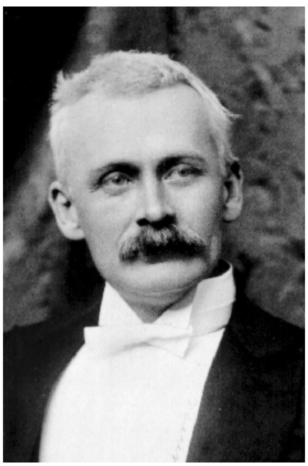
PICTURE. From K. LEHMANN: *Ludger MINTROP, der große Markscheider und Geophysiker* (*see above*).

MUNROE, Charles Edward (1849–1938)

▪ U.S. chemist and high explosives specialist; father of explosive engraving and explosive forming



Charles E. MUNROE was born in East Cambridge, MA, to Enoch MUNROE, an instrument maker. He studied at the Scientific Department of Harvard University, where he graduated in 1871. After having assisted Prof. Willard J. GIBBS, he remained there as an instructor in chemistry (1871–1874). In 1872, he conducted a summer course of instruction in chemistry for teachers in Cambridge, MA, which was the first of its kind. In 1874, he was called to the chair of chemistry at the U.S. Naval Academy (Annapolis, MD), where he remained for 12 years, in addition to lecturing at St. John's College (1883–1884) in Annapolis. He then accepted the appointment of chemist to the U.S. Torpedo Station and War College (Newport, RI), where he made practical demonstrations in the manufacture, testing, and use of high explosives. He was also frequently called by national authorities to conduct special investigations on explosives. Subsequently, he took the chair of chemistry at Columbian College in Washington, DC (1892) and became dean of the School of Graduate Studies connected with that institution. He received his Ph.D. from Columbia University, New York City in 1894. Later he became a consultant to numerous governmental agencies and acted as chairman of various commissions.

Because of his employment in the Navy his work was closely affiliated with military explosives. For example, he invented a stable and effective naval smokeless cannon powder, so-called "indurite" (1891), which was especially commended by U.S. President Benjamin HARRISON in an annual address to Congress.

MUNROE accidentally observed how to shape explosives to concentrate energy – later called the "Munroe effect" (1888) – thus rediscovering the "unlined shaped-charge effect," which had already been discovered twice before in Germany (by Joseph VON BAADER in 1792 and by Max VON FÖRSTER in 1883) and thereafter fallen into oblivion. MUNROE noticed that when a block of guncotton with the manufacturer's name stamped into it was detonated next to a metal plate, the lettering was cut into the plate; if letters were raised in relief above the rest of the guncotton then the letters on the plate would also be raised above its surface. MUNROE used his discovery to imprint designs on iron plates by interposing a stencil between the explosive and plates of iron, thereby laying the foundation for a new technique – so-called "explosive engraving." The adjacent surfaces of a cavity in the explosive collide, as a result of which the so-called "Munroe jet" is generated. By the turn of the century, he had recognized the possibility of forming metals using shaped charges of explosives, a concept that also formed the basis for shaped charged used so efficiently during World War II.

In the late 1890s, he participated at the Naval Proving Ground in the perfection of an armor-piercing high explosive shell that would detonate within a battleship through the agency of a delayed action fuse. He was able to prove that a loaded shell could be made to stand such a shock of impact and penetration and then to explode on the inner side of a 14.5-in. (37-cm) plate of Harveyized armor (a case-hardened plate armor based upon an invention made by the American Hayward A. HARVEY in order to strengthen armor plating for warships).

Besides publishing several books and over 100 scientific papers on chemistry and explosives, he also did a great deal

of bibliographic work and compiled an *Index to the Literature of Explosives* (1886, 1893). MUNROE was elected vice president of the Chemical Section of the American Association for the Advancement of Science (1887) and president of the Chemical Society of Washington (1895) and the American Chemical Society (1898). He received many honors and was a member of the American Academy of Arts and Science, the American Philosophical Society, and the Washington Academy of Sciences. He was also a foreign member of the Chemical Society London and the Deutsche Bunsen Gesellschaft (German Bunsen Society). In 1900, he was appointed by the Royal Swedish Academy of Sciences to nominate the candidate for the Nobel Prize in chemistry.

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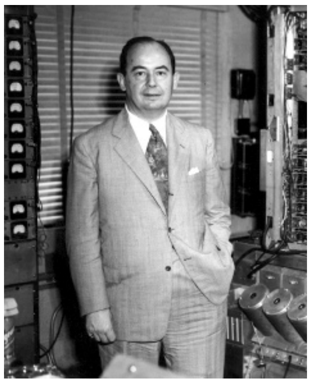
PICTURE. Courtesy Deutsches Museum, Munich, Germany.

NEUMANN, John [born Johann] Louis VON (1903–1957)

▪ Hungarian-born U.S. mathematician and theoretical physicist; father of three-shock theory and cofounder of modern detonation theory



John L. VON NEUMANN was born in Budapest to Max VON NEUMANN, a wealthy Jewish banker. He studied first chemistry and then mathematics at the University of Berlin. In 1926, he received his diploma in chemical engineering from the Eidgenössische Technische Hochschule Zürich (ETHZ) and in the same year his doctorate in mathematics from the Pázmány Péter Tudományegyetem (Péter Pázmány University) in Budapest. After a period of lecturing as *Privatdozent* (university lecturer) at the Universities of Berlin (1927–1929) and Hamburg (1929–1930), he became a visiting lecturer (1930) and full professor (1931–1933) at Princeton University. Invited to join the newly founded Institute for Advanced Study (IAS), he became the youngest member of its permanent faculty and professor of mathematics – a position at Princeton that he kept for the remainder of his life.

VON NEUMANN's contributions cover a wide spectrum of contemporary scientific thought, such as quantum mechanics, theory of games and economics, computer science, nu-

merical methods for solving nonlinear partial differential equations, and hydrodynamics. In 1932, he wrote a major work on the mathematical foundations of quantum mechanics. From the mid-1930s he was interested in hydrodynamic turbulence. In 1937, VON NEUMANN had long discussions with Stanislaw ULAM, a mathematical physicist and spiritual father of the fusion bomb, on the phenomenon of turbulence and the possibility of a statistical treatment of the Navier-Stokes equations. VON NEUMANN proposed to analyze hydrodynamical problems through replacement of the partial differential equations by a system of infinitely many total differential equations, satisfied by the Fourier coefficients in the development of the Lagrangian functions in a Fourier series. During World War II, he was invited by Robert OPPENHEIMER to bring to the implosion program his expertise on theoretical hydrodynamics and ability to solve sets of nonlinear partial differential equations numerically.

Independently of Yakov B. ZEL'DOVICH in the Soviet Union and Werner DÖRING in Germany, VON NEUMANN became engaged in the theoretical treatment of the detonation process. He improved the Chapman-Jouguet (CJ) theory by introducing a reaction zone – the so-called "Zel'dovich-von Neumann-Döring (ZND) theory." On a theoretical basis he first treated the propagation and oblique interaction of shock waves, which he classified into "regular reflection" and "Mach reflection." He performed the task of selecting the most effective Height of Burst (HOB) for the atomic bombs on the Japanese targets, made valuable proposals to the implosion method for bringing nuclear fuel to explosion, and also participated in the development of the hydrogen bomb.

After the war his interest in hydrodynamics continued, and he established a meteorological research group to tackle the mathematical problems of solving the hydrodynamic equations of the motions of the Earth's atmosphere for numerical weather prediction. Together with Stanislaw ULAM he invented the Monte Carlo method (1946), a mathematical procedure to model a complex problem stochastically, and together with Arthur W. BURKS and Herman H. GOLDSTINE he developed the idea of a parallel, stored-program electronic computer (1946–1948), a landmark in the history of computer science that was taken up and applied by most subsequent digital computer designers. At IAS he developed the so-called "IAS Computer," the first computer designed as a general purpose system with stored instructions which was optimized for scientific calculation and became operational in 1952.

From 1937, VON NEUMANN was a member of the National Academy of Sciences (NAS). In 1955, U.S. President EISENHOWER appointed him to the Atomic Energy Commission (AEC). In the following year, he received the Medal of Freedom and the AEC Enrico Fermi Award. Shortly thereafter, he died of cancer in a hospital in Washington, DC at the age of 53.

His pioneering contribution to various fields of science and technology have been widely acknowledged, and a number of terms are named for him: in detonation physics the *von Neumann (vN) spike* and the *vN state* of a detonating high explosive; in shock wave physics the *vN reflection*, the *vN criterion* and the *vN paradox*; in numerical analysis the *vN analysis*; and in computer technology the *vN architecture* and the *vN machine*.

The *John von Neumann Lecture*, a prize established in 1959 by the Society for Industrial and Applied Mathematics (SIAM), is awarded "for outstanding and distinguished contributions to the field of applied mathematical sciences and for the effective communication of these ideas to the community."

A crater on the far side of the Moon is named for him.

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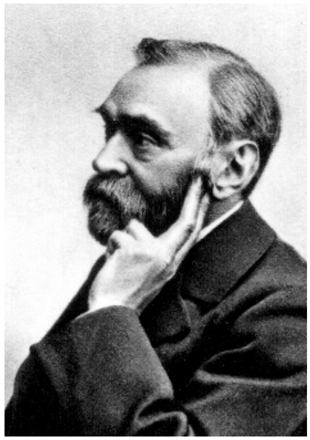
PICTURE. Taken in the early 1950s by Alan RICHARDS, showing VON NEUMANN in front of the IAS computer which was built under his direction. Courtesy Institute for Advanced Study (IAS), Princeton, NJ.

NOBEL, Alfred Bernhard (1833–1896)

▪ Swedish chemist, inventor, and industrialist; founder of the Nobel Prizes



Alfred B. NOBEL was born the son of Immanuel NOBEL, a financially successful inventor and businessman of war materiel, and was destined to follow in his energetic father's footsteps in many ways. When the family moved to St. Petersburg, Russia for business purposes, he and his two brothers were tutored privately (1843–1850). After studying engineering at St. Petersburg and chemistry in other European countries and the United States, he returned to St. Petersburg. In 1859, his father's company had to declare bankruptcy, because the Russian government cancelled all delivery agreements after it lost the Crimean War (1853–1856). His father began to experiment with nitroglycerin, which had been invented by the Italian chemist Ascanio SOBRERO (1846), but hitherto could not be applied in practice because of its extreme sensitivity to shock and heat.

His father developed a method of producing nitroglycerin on a factory scale, and in Heleneborg, an isolated area outside of Stockholm, he put the world's first factory, Nitroglycerin Ltd Stockholm, into operation (1865). Already in 1863 NOBEL invented the *detonator cap* (charged with mercury fulminate) to detonate a liquid nitrogen explosive charge by a strong shock wave rather than by heating. Since the time instant of ignition could be determined with great precision, his invention became very important for all future applications of multiple-charge arrangements, particularly for all shock techniques based on shock wave interactions and implosion. After a long period of experimentation he patented *dynamite* (1867), initially a mixture of about 75%

nitroglycerin and 25% kieselguhr, the latter strongly absorbing the nitroglycerin, thus allowing one to handle dynamite more safely without substantially reducing the explosion efficiency. In 1875, he patented the use of active ingredients in dynamite and called the material "blasting gelatin" – also known as "oil well explosive" – a rubber-textured, water-resistant explosive made by adding nitrocellulose (guncotton) to nitroglycerin, which has a very high detonation velocity and, therefore, a greater blasting action power than dynamite. His fourth great invention was *ballistite* (1888), a smokeless blasting powder and excellent propellant that essentially contains nitroglycerin and nitrocellulose. It was used for over 75 years.

NOBEL settled in Paris (1873) and made many other inventions such as various improvements in gas burners, an automatic brake, a system of non-explodable boilers, a refrigerating apparatus, and methods of vaporizing liquids and purifying cast iron. In 1883, he obtained permission from the French government to place a cannon and establish a small shooting range in an abandoned fort close to his laboratory at Sevran, 16 km northeast of Paris – a village that had become the late-19th-century French capital of gunpowder and explosives. At the end of his life he held more than 350 patents in different countries, covering detonics, electrochemistry, metallurgy, biology, optics, and physiology. NOBEL became a wealthy man and left his estate to establish annual prizes, the so-called "Nobel Prizes," for outstanding achievements (since 1901 in physics, chemistry, medicine and physiology, peace, and literature, and since 1969 in economics). The Norwegian Nobel Institute assists the Nobel Committee in the task of selecting the recipient of the Nobel Peace Prize and organizes the annual Nobel events in Oslo.

The radioactive element "nobelium" (No; atomic number 102, mass number 253) was named in his honor. Not occurring in nature but first suggested in 1957 by a team of scientists at the Nobel Institute for Physics in Stockholm, it was eventually identified in 1958 at the University of California at Berkeley. The team produced it by bombarding curium with high-energy carbon nuclei.

A crater on the far side of the Moon and a minor planet (asteroid 6032 NOBEL) are also named for him.

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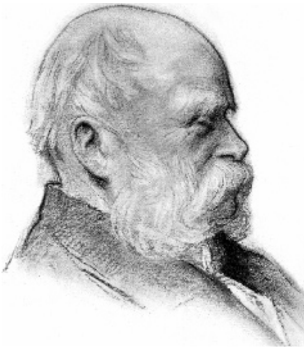
PICTURE. Courtesy Deutsches Museum, Munich, Germany.

NOBLE, Sir Andrew (1831–1915); from 1902 first Baronet

▪ British physicist, gunnery expert, and industrialist

Sir Andrew NOBLE was born in Greenock, Scotland. He was the third son of George NOBLE, a retired naval captain. He was first educated in Greenock and later at Edinburgh Academy and the Royal Military Academy at Woolwich, southeast London. He entered the Royal Artillery (1849), rose to be Captain (1855), and was appointed secretary to the Select



Committee on the Relative Merits of Smoothbore and Rifled Cannon and assistant inspector of artillery (1858). In the same year, the new system of breech-loaded artillery – superior to smooth-bore guns as proved by NOBLE in numerous scientific experiments and accurate observation – was adopted officially by the armed services. He also became a member of the Committee of Explosives.

After serving 12 years with his regiment in Canada and South Africa, he resigned his commission (1860) and joined Sir William George ARMSTRONG, a mechanical engineer and inventor who, emphasizing rifled bores and elongated projectiles, had just established ordnance works at Elswick, from 1882 named W.G. Armstrong & Co., which in 1897 merged with Whitworth & Co. In 1861, he became ARMSTRONG's partner and operational head of the company. After ARMSTRONG's death he rose to the position of chairman (1900).

In his interior ballistic experiments NOBLE followed earlier investigators such as Thomas J. RODMAN and Sir Benjamin THOMSON, Count VON RUMFORD; however, he carried the examination of fired gunpowder further than any of his predecessors. In order to measure the velocity of a projectile in its passage through the bore, he invented a special chronoscope for use in ballistics – the so-called "Noble chronograph" (1862) – a device for measuring very small time intervals. His instrument was essentially an improvement over the Navez chronograph, by which the velocity of a shot at any point in traveling down the bore of a gun could be ascertained. Using Sir Isaac NEWTON's Second Law of Motion, this technique gave him the means for calculating the effective mean pressure on the base of a projectile and of coupling this with the indications of his "crusher gauges," certainly his most renowned invention that, being a derivative of RODMAN's indentation gauge but more accurate, was soon used worldwide. The results of his research activities on the nature and products of explosion and other particulars in connection with this little known branch of science and guns that he jointly performed with Sir Frederick ABEL were later published in a two-part monograph under the title *Researches on Explosives* (1875, 1880). His thorough studies, which put this subject upon a scientific basis and established the science of ballistics, did much to advance the manufacture of guns and gunpowder. This resulted in longer guns with larger chambers and slower burning powders, thus superseding the use of hand-rammed black powder.

NOBLE was elected F.R.S. (1870), and awarded the Royal Medal (1880) and the Albert Medal of the Royal Society of Arts (1909). He received the honorary degree of Doctor of Science from Oxford University and was created a baronet (1902). He was a member of various orders of knighthood.

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OPPENHEIM, Antoni ("Tony") Kazimierz (1915–)

▪ Polish-born U.S. aeronautical engineer, gas dynamicist, and combustion specialist

Antoni K. OPPENHEIM was born in Warsaw. His father, Tadeusz OPPENHEIM, was an industrialist and ceramic engi-

neer, and his mother came from an industrial family. His ambition was to become an engineer, and after graduation at the Gymnazjum of Wojciech Gorski (1933) he entered the Politechnika Warszawska (Warsaw University of Technology). With the collapse of Polish resistance after the outbreak of World War II, OPPENHEIM began his odyssey from Poland to England, where he arrived in June 1940 after many adventures. On leave from the artillery of the Polish army in Scotland (1942), he enrolled as a student at the City and Guilds College, the engineering branch of the Imperial College of Science and Technology, University of London, to complete requirements for his degree from Warsaw University of Technology. In 1945, he passed the final examination for the degree of *Dipl.-Inz.* before an Anglo-Polish committee appointed by the Ministry of Education of the Polish government in exile and completed his studies of high-speed flow of gases in channels for a Ph.D. at the University of London, in conjunction with a DIC (Diploma of Imperial College). There he became a lecturer, teaching heat transfer and gas dynamics, and, with his postgraduate students, built the first supersonic wind tunnel.

His career as a scientist was launched by Sir Owen SAUNDERS, a reader in the Mechanical Engineering Department at the City and Guilds College who received a proposal from the Napier Engine Co. to investigate the possibility of improving the performance of its piston engines used in the British fighter planes Spitfire and Hurricane. He assigned the proposal to OPPENHEIM, who worked out an analytical solution demonstrating how the total thrust (propeller plus exhaust jet) could be augmented. OPPENHEIM, having been granted an indefinite leave of absence from the Polish army, was employed by Power Jets (Res. & Dev.) at Whetstone, Leicester, U.K., which was formed in 1936 under the directorship of Sir Roxby COX, a British aeronautical engineer, to develop the gas turbine jet propulsion engine of Frank WHITTLE. Progress made on the thrust augmentation project was swift: in a few months, all the exhaust manifolds of fighter engines were replaced by individual nozzles and the valve timing adjusted for maximum total thrust. Top aircraft speed was thereby increased, giving British pilots an advantage over their German adversaries. OPPENHEIM conducted a study of secondary air mixing in the turbine combustion chamber that led to the development of the canister type, the universally accepted standard. He demonstrated that nozzles are redundant for this purpose; holes are quite sufficient.

Analyzing the operational mechanism of the pulsed jet engine that powered the German V1 (or "Flying Bomb"), he developed a systematic approach to 1-D gas dynamics that led to a paper with Joseph KESTIN on the generalized entropy chart. Published by the Institution of Mechanical Engineers, the paper won a prize for best technical article (1948). After the war, he was sent to Germany as a British intelligence objectives subcommittee officer to solicit reports from the principal scientists and engineers involved in the development of the pulsed jet engine. To obtain a value for the speed of the exothermic front that was required for the gas dynamic wave interaction analysis of this engine type, OPPENHEIM became involved in detonation phenomena – an effort that led him to the development of the theory of a double discontinuity system and its Q-curve and the locus of states immediately behind it.

After an appointment as assistant professor (1948–1950) at Stanford University, he was appointed assistant professor (1950–1954) at the University of California at Berkeley, where he was promoted to associate professor (1954–1958) and professor of mechanical engineering (1958–1986). In addition, as a staff consultant at Shell Development Co. (Emeryville, CA), he gained an impressive amount of knowledge in physical chemistry. At UC Berkeley his studies included the development of the radiation network method, the theory of heat transfer in free molecular flow, the use of vector polar methods for the analysis of interactions and intersections between gas dynamic wave fronts, the development and structure of detonation fronts, blast wave theory, turbulent combustion, plasma jets, turbulent jet plumes, and controlled combustion in engines. The common denominator of all studies throughout his career was his fascination with the combustion dynamics of exothermic systems in terms of the fundamental components: thermodynamics, thermochemistry, and aerodynamics.

OPPENHEIM was an active member of various professional and honorary societies. He organized the Northern California Section of the American Rocket Society (ARS), served as its president (1957), and was elected member of the ARS National Board of Directors. He also served on the NASA Research Advisory Committee on Fluid Mechanics (1963–1968). He was deputy editor of Combustion and Flame (1972–1973), associate editor of Astronautica Acta (1973), and editor-in-chief of Acta Astronautica (1974–1978). He

was executive cochairman of the International Committee on Dynamics of Explosions and Reactive Systems (1966–1983) and organized the International Colloquium on Dynamics of Explosions and Reactive Systems (ICDERS). From 1952 was an active participant in the Symposium (International) on Combustion.

He took several sabbatical leaves, which he spent in Poitiers at the Ecole National de Mécanique et Aérothermodynamique (Prof. Numa MANSON), at the University of Marseilles (Prof. Paul CLAVIN), and in Göttingen at the MPI für Physikalische Chemie (Prof. Heinz G. WAGNER). During his tenure as a professor of engineering at UC Berkeley, he was also a visiting professor at the Sorbonne (1960–1961), a Miller Professor at UC Berkeley (1961–1962), and a Professeur Associé at the University of Poitiers (1973 and 1980). OPPENHEIM was author or coauthor of over 300 papers and supervised 21 M.S. and 34 Ph.D. students. He received numerous awards and honors from national and international societies and universities.

In 1989, the Institute for Dynamics of Explosions and Reactive Systems (IDERS) introduced the *Oppenheim Prize* to be awarded for "brilliant contributions to the theoretical or interpretive aspects of the dynamics of explosions and reactive systems."

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PICTURE. Courtesy Dept. of Mechanical Engineering, UC Berkeley, CA.
NOTE. The short biography was kindly provided by Dr. Allen L. KUHL of LLNL, Livermore, CA.

OSWATITSCH, Klaus (1910–1993)

▪ Austrian physicist and gas dynamicist

Klaus OSWATITSCH was born in Marburg on the Drau, at that time part of the Austro-Hungarian Empire (now Maribor, Slovenia). His father was a judge of high rank. After studying physics and mathematics at the University of Graz and graduating (Dr. phil. nat. 1935), he also took the examinations for a grammar-school teacher (1938) to better cope with the bad economic situation of that time. Provided with a fellowship from the Deutsche Forschungsgemeinschaft (German Research Community), he joined Prof. Ludwig PRANDTL at the Kaiser-Wilhelm-Institut für Strömungsforschung in Göttingen and became *Privatdozent* (university lecturer) at the University of Göttingen (1942–1946), in addition to also carrying out research for the Heereswaffenamt (Army Ordnance Office). After the war he worked briefly for the Royal Aircraft Establishment at Farnborough (1946) and for the French military in the Bureau d'Etudes at Emmendingen, Baden (1947). In the following years, he lectured in Germany (1948–1949) at the University of Freiburg and in Sweden (1949–1956) at the Kungl. Tekniska Högskolan (KTH), the Stockholm Polytechnic. In 1956, he established and headed at Aachen the Institut für Theoretische Gasdynamik of the Deutsche Versuchsanstalt für Luft- und Raumfahrt (DVLR). In 1960, he was appointed full professor at Vienna Technical University, where he worked until his retirement (1980).

His research covers a broad spectrum of gas dynamics and treats many problems relating to supersonic flow and shock waves, such as (1) condensation phenomena in supersonic nozzles, (2) supersonic flow around delta wings and in cascades of turbines, (3) hypersonic flow, (4) the development of effective shock diffusers, (5) 3-D flow around slender bodies at all Mach numbers, (6) supersonic intake design of high-speed aircraft engines using oblique shocks to give high efficiency, (7) analysis of gas dynamic phenomena in transitional ballistics, and (8) sonic boom and other acoustic phenomena associated with the muzzle blast and explosions. In particular, OSWATITSCH dedicated himself to understanding transonic flow phenomena, which became important for the design of supersonic aircraft.

He published more than 120 papers, 3 handbook articles, and 7 books. He belonged to the board of editors of various professional journals and was chairman of the first and second Symposium Transsonicum (1962, 1975) and editor of the proceedings. His famous textbook *Gasdynamik* (1952), which was also translated into English and Chinese, is certainly his best-known work. OSWATITSCH edited volume 7 (*Two-phase flows*, 1977) of the *Vieweg Tracts in Pure and Applied Physics*. Together with Karl WIEGHARDT he edited the 8th and 9th editions of Ludwig PRANDTL's *Führer durch die Strömungslehre* (1984, 1990).

He received many honors and became an honorary member of many scientific societies. He received honorary doctorates from the Universität Karlsruhe, KTH, and ETHZ.

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PICTURE. Courtesy Archives of TU Vienna, Austria.

PAPIN, Denis [Lat. *Dionysius*] (1647–1712?)

▪ French-born British natural philosopher and inventor; father of the steam and piston engine

Denis PAPIN was born in Blois (Dépt. Loir-et-Cher) the son of Denis PAPIN, a royal counselor and district revenue collector. After attending a local Jesuit school, he graduated (M.D.) from the medical faculty of the University of Angers (1669). However, shortly afterwards he embarked upon a scientific career and worked closely with renowned scientists of his time. In Paris he became an assistant (1671–1674) to the Dutch natural philosopher Christiaan HUYGENS, who had been invited by the Paris Academy to develop his many scientific interests under French protection. In London he worked with Robert BOYLE on experiments connected with respiration, magnetism, air, and the chemistry of blood and various medicaments (1675–1679). At the Royal Society of London PAPIN became assistant (1679–1680) to Robert HOOKE. After briefly working again with HUYGENS in Paris (1680), he was appointed director at Ambrose SAROTTI's Accademia Publicca di Scienze (Public Academy of Science) in Venice (1681–1684). Since the Edict of Nantes was revoked in 1685 and PAPIN belonged to a Huguenot family, he did not return to France, but rather became an exile. After working again for the Royal Society in London (1684–1687), PAPIN went to Germany. He became professor of mathematics at the University of Marburg (1687–1696), and in Kassel he served as counselor to the landgrave Karl VON HESSEN-KASSEL (1695–1707). After 20 years he eventually returned to London (1707) but did not receive an appointment from the Royal Society and died in London in poverty (around 1712).

PAPIN was a skillful experimenter and invented various machines; the best known are an air pump (1675), his "steam digester" with the first "safety valve," which he demonstrated in London to the Royal Society (1679), and an atmospheric-pressure piston steam engine for pumping water (1690), a forerunner of the low-pressure steam engine as patented by Thomas SAVERY (1698) and developed by Thomas NEWCOMEN (1712). PAPIN's safety valve was also used in many steam engines.

Prior to his steam experiments Papin improved and realized Huygens' idea of a *pompe balistique* (piston ballistic pump) which, by applying gunpowder to generate a vacuum in a combustion cylinder, used the atmospheric pressure to perform work – particularly to operate a pump to raise water from the Seine river to the palace of Versailles. Papin's "gunpowder machine," which he described in his first treatise *Nouvelles expériences du vuide* ("A New Vacuum Experiment," 1674) and the principle of which he had successfully demonstrated on a model, was an early example that inspired subsequent inventors to try to use the chemical energy of explosives for periodically driving machines. The abolition of a bulky steam generator appeared very attractive to reduce weight, but the principle was still too ambitious of that time. In addition, other problems, such as achieving controlled ignition, coping with cylinder erosion, and managing detrimental shock and vibration effects in such a machine, were not even touched.

In 1839, the Syndicat Général des Industries Mécaniques et Transformatrices des Métaux de France – choosing Papin as their "mentor," considering that mechanical engineering would not exist without the engine – created the *Papin medal*.

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PICTURE. Courtesy Bildarchiv Foto Marburg, Germany; image No. 206282.

NOTE. A computer animation showing the operation cycles of Papin's ballistic pump, the basic design for early steam engines, can be watched in the Internet; *see* http://www.geocities.com/Athens/Acropolis/6914/pappe.htm.

Payman, William Henry (1896–1946)

▪ British physical chemist and combustion specialist

William H. Payman was educated at the Universities of Manchester and Sheffield. After graduating at the Manchester College of Technology (1915), he began a postgraduate study of the inflammation of gas mixtures under the guidance of Dr. Hubert Frank Coward, with whom he was again to become associated in later years. He became a demonstrator in chemistry and later joined the staff of the Home Office Experimental Station at Eskmeals, Cumberland (1917), an organization directed by Prof. Richard V. Wheeler and devoted to the examination of explosion hazards in coal mines which later expanded into the Safety in Mines Research Board (SMRB), with stations at Buxton and Sheffield. In the period 1919–1922, he formulated his "law of flame speed"

in mixed gases, which brought him into a sharp controversy with Prof. William A. BONE, head of the chemistry department at the Imperial College and a renowned fuel technologist. Later he became principal officer of the SMRB (1926) and transferred his attention to the safe use of explosives in coal mines.

Little was known about the hazard of explosives when fired in contact with firedamp and which mechanism for triggering firedamp explosion would be dominant, the contact with flame or by adiabatic compression of the shock wave. To investigate these problems experimentally in greater detail, PAYMAN's team developed the "flame speed camera," an instrument that was used chiefly for photographing slowly moving and feebly actinic flames, and his "wave-speed camera," which allowed photography of all kinds of flames and shock waves. His original contributions to this new field of research were recognized by the award of the D.Sc. degree by the University of Manchester (1929). In his address to the participants of the First Conference on Safety in Mines (1931), which took place at Buxton Research Station, the seat of his laboratory, he summarized the present state of his applied methods and the experimental results thus obtained. Topics of practical importance were the two questions (1) whether a shock wave alone could start an explosion in a firedamp/air mixture without the aid of the flame or hot gases from an explosion and (2) why an explosive sometimes does and sometimes does not ignite firedamp. Later he supervised research on mining explosives and during most of the war conducted a large program of work on explosives that the SMRB carried out for the Ministry of Supply. In 1940, PAYMAN and coworkers performed a number of interesting shock-tube studies: they measured the shock front velocities for various combinations of driver gas and operation gas and found that stronger shocks could be achieved with a combination of hydrogen/air rather than with one with air/air. They were the first to observe a vortex ring generated by diffraction of a shock wave from the open end of a shock tube (not published until 1946).

PAYMAN's contributions are recorded in numerous papers in the Journal of the Chemical Society. He was also coauthor with Prof. I.C. Frank STATHAM of a monograph on *Mine Atmospheres* (1930), which addresses the hazards of firedamp explosions and mine fires originating from methane and carbon monoxide, and the role of mine dust and moisture. He achieved international recognition in 1938 when he was appointed president of the Explosives Section of the Congress of Applied Chemistry held at Nancy, France. He was also for some years secretary of the informal Explosives in Mines Research Committee of the SMRB. He died at the age of 50 after a short illness.

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PICTURE. Courtesy Mr. Mike EGGENTON, Health & Safety Laboratory, Sheffield, U.K. The photo shown is an enlargement of a group photo taken at the 1st Int. Conf. on Safety in Mines at Buxton, U.K. (July 1931).

POISSON, Siméon-Denis (1781–1840)

▪ French mathematician, physicist, and astronomer; early pioneer of nonlinear acoustics

Siméon-Denis POISSON was born in Pithiviers, a small town near Orléans (Dépt. Loiret). His father, Siméon POISSON, had first chosen a military career and later became a notary. Brought up in a family of modest means, he was originally supposed to apprentice in surgery but showed little interest in this profession. At the Ecole Centrale de Fontainebleau his teacher discovered his interest in mathematics. He entered the prestigious Ecole Polytechnique, Paris (1798) and his teachers, Pierre-Simon DE LAPLACE and Joseph L. DE LAGRANGE, were impressed by his abilities and became his lifelong friends. After graduation (1800) he taught at the Ecole Polytechnique, and, drawn to the problems of integrating differential and partial differential equations, he began to look for applications in physics.

It appears that POISSON, stimulated and supported by DE LAPLACE, was the first to correctly recognize that sound is an adiabatic process, and that the adiabatic equation of state for a gas is given by $pV^{\gamma} =$ const, the so-called "Poisson law" or "Poisson isentrope." Here γ is the ratio of specific heats at constant pressure and volume. Using this adiabatic law he worked out the first theory of sound of finite amplitude (1808), thus laying the theoretical foundations of nonlinear acoustics and paving the way for James CHALLIS, George STOKES, Samuel EARNSHAW and Bernhard RIEMANN to mathematically investigate waves of finite amplitude (*i.e.*, shock waves) in more detail. Shortly afterwards, he acted as an astronomer at the Bureau des Longitudes and was appointed chair of pure mathematics in the newly opened Faculté des Sciences (1809). As a member of the Conseil Royal de l'Université (1820–1840) he was intimately familiar with actual problems of national education at the highest administrative level.

He contributed significantly to the theory of differential equations and partial differential equations, game theory, and probability and today is regarded as one of the most eminent founders of modern mathematical physics. Being mostly concerned with applications of mathematics to physics, his numerous investigations advanced the progress of physics of his time, particularly in mechanics (elasticity), hydrodynamics (waves in deep water), heat conduction, electricity, celestial mechanics, gravitation, and cosmology. He also originated one of the first mathematical theories of electrostatics and magnetism. In his *Traité de mécanique* (1811, 1833), which became the standard work in mechanics for many years, he treated billiards, percussion of bodies of arbitrary geometry, and longitudinal percussion of elastic bars (*see* vol. II, chaps. 7 and 8 of his book). Stimulated by the discovery of the Coriolis effect (1835), POISSON made an analysis on the deflection of artillery shells. He ruled out any effect on a swinging pendulum which, however, was refuted by FOUCAULT's historical pendulum experiment (1851).

POISSON published around 350 papers and received many prestigious awards such as the Copley Medal (1832). He was a Fellow of the Royal Societies of London (1818) and Edinburgh (1820). He was a member of the French Academy of Science and all the scientific societies in Europe and America and an honorary member of the St. Petersburg Academy of Sciences.

In the theory of elasticity, the *Poisson ratio* is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. In applied mathematics the *Poisson integral* is used in boundary-value problems. In electricity the *Poisson equation*, a partial differential equation, relates the potential to the distribution of charges; for many charges distributed randomly it allows one to calculate the dependency of the potential on the coordinates.The Poisson eqution is also used in mechanical engineering and theoretical physics. In probability theory he derived a for-

mula known as the "Poisson distribution." A *Poisson process* is a stochastic process which is defined in terms of the occurrence of events. The *Poisson regression model* is often used to analyse count data and is fitted as a log-linear regression.

Astronomers named a crater on the near side of the Moon and a minor planet (asteroid 12874 POISSON) after him.

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POULTER, Thomas Charles (1897–1978)

▪ U.S. physicist, engineer, biosonic researcher, and inventor

Thomas Ch. POULTER was born and raised 8 miles south of Mt. Pleasant on his father's farm near Salem in the State of Iowa. His father, Micajah Louis POULTER, was a farmer and mechanic who operated a blacksmith shop part time in Salem. He graduated from Iowa Wesleyan College (1923) and was appointed professor of physics at that college (1923–1933), where he served as head of the chemistry and physics departments and the physical sciences, mathematics, and astronomy division. His most prominent student was James A. VAN ALLEN, the renowned U.S. astrophysicist, who worked as a part-time student assistant in his high-pressure research laboratory. He completed graduate work at the University of Chicago, receiving his Ph.D. in chemistry (1933). Sound and vibrations, and high pressures, both static and dynamic, were the constant unifying motifs of his scientific curiosity throughout his life. His other interests included organic chemistry, terrestrial magnetism, and Antarctic meteorological and auroral phenomena.

In the fall of 1932, POULTER took a group to the southwest United States to explore the activity of meteors. During Admiral Richard BYRD's Antarctic Expedition over the South Pole (1933–1935) he participated as second in command and chief scientist. He performed explosive seismic surveying, and using sky "reticles," which he devised and built from welding rods, he obtained the world's most comprehensive sets of observations of meteor trails at that time. He became first scientific director of the Armour Research Foundation of the Illinois Institute of Technology (IIT) in Chicago (1936–1948), where he designed the Antarctic snow cruiser used on the U.S. Antarctic Service Expedition, on which he served as scientific advisor (1939–1940). He made a total of 15 trips to the Artic and 3 to the Antarctic. As a result of techniques discovered in the Antarctic seismic studies he invented a seismic method to map underground strata by analyzing reverberations from surface explosions, so-called "air shooting" or "Poulter seismic method." It uses explosive

charges detonated in the air or on poles above the ground as the source. Initially applied to measuring ice thickness on Taku Glacier, Alaska (1949), it was later also applied in other geophysical explorations.

After World War II, he conducted considerable research on detonation (such as the construction and use of shaped charges for oil well completion) and on shock pulse phenomena. His expertise in detonating explosives led to military research on shock wave and detonation phenomena related to the development of new types of nuclear weapons. He joined the Stanford Research Institute (SRI) at Menlo Park, CA as an associate director (1948) and established the Explosives and Extreme Pressure Laboratory of SRI (1953), which in 1956 was named after him ("Poulter Laboratory") for his contributions in the fields of detonation and shock pulse phenomena. He also established the Calaveras Test Site, an explosives test facility in the mountains in Calaveras County, CA. POULTER became scientific director and general manager of SRI's physical and life sciences divisions (1960). After his retirement he developed the Biological Sonar Laboratory, a private research center in Fremont Hills, CA, where he studied how marine mammals – such as seals and sea lions – hear and how they use acoustic information (1962–1973). Subsequently, he cooperated with the UC Medical School in San Francisco in a project to restore hearing in totally deaf people.

POULTER held more than 75 patents on diverse inventions. He authored more than 100 articles, books, and publications and received the Geographic Medal (1937) of the National Geographic Society and two Congressional Medals of Honor for polar exploration. From 1973 he was an honorary member of the American Polar Society.

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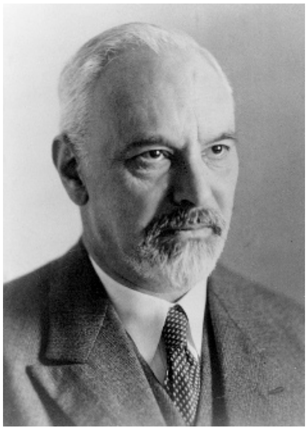
PICTURE. From SRI-Journal *Spectrum*, SRI International, Menlo Park, CA (July/Aug. 1978).

PRANDTL, Ludwig (1875–1953)

▪ German engineer and physicist; father of modern fluid dynamics and aerodynamic theory

Ludwig PRANDTL was born in Freising, Upper Bavaria. His father, Alexander PRANDTL, was a professor of surveying and engineering at the Weihenstephan Agricultural College. He showed an early interest in technical matters. After studying mechanical engineering at the Technische Hochschule (TH) Munich (1894–1898), he took his Ph.D. (1900) at the University of Munich with a thesis on elastic stability, entitled *Kipperscheinungen, ein Fall von instabilem elastischen Gleichgewicht* ("Tipping Phenomena, a Case of Instable Elastic Equilibrium"). His thesis supervisor was August FÖPPL, an internationally renowned expert in mechanics who later became his father-in-law. As a scientific employee



(1900–1901) at the Maschinenfabrik Augsburg-Nürnberg (MAN) he solved practical problems such as how to remove shavings from machine tools by suction, and thereby had his first exposure to fluid mechanics, particularly aerodynamics – a field to which he dedicated the rest of his life.

After successfully solving the problems at MAN he became shortly thereafter professor at the TH Hannover (1901). Later, in pursuit of Felix KLEIN, he became *Extraordinarius* (professor without chair) of technical physics (1904) and *Ordinarius* (professor with chair) of applied mechanics (1907–1947) at the University of Göttingen, where he continued working as professor emeritus until his death. In 1907, he initiated the foundation of the Aerodynamische Versuchsanstalt (AVA) Göttingen. In 1925, PRANDTL was appointed director of the newly established Kaiser-Wilhelm-Institut (KWI) für Strömungsforschung. To scientifically support the German aircraft industry he was cofounder of the Wissenschaftliche Gesellschaft für Luftfahrt Berlin (1912) and became member of its executive board. PRANDTL presented in 1904 a paper *Über Flüssigkeitsbewegung bei sehr kleiner Reibung* ("On the Motion of a Fluid with a Very Small Viscosity"), which marked an epoch in the history of fluid mechanics: his discovery of the "boundary layer" that adjoins the surface of a body moving in a fluid led to an understanding of skin friction drag and of the way in which streamlining reduces the drag of airplane wings and other moving bodies. He also supervised the installation of Germany's first wind tunnel (1907–1909), a closed-circuit facility intended for aerodynamic testing of Zeppelin models that had a cross section of 2×2 m^2, a maximum speed of 36 km/h (10 m/s), and was operated at a power of 35 hp. After development of a more powerful, 300-hp wind tunnel (1915–1917), a full-scale device with a maximum speed of 50 m/s was eventually completed for propeller and air wing research (1933).

His numerous publications cover a wide range of research in fluid mechanics: he contributed to low-speed airfoil theory as well as to the theory of supersonic flow, first visualized oblique shock and expansion waves in Laval nozzles, investigated induced wing drag and the role of boundary vortices, studied compressibility effects at high-speed flight, and invented the *Prandtl tube* (1913), which allows one to determine the dynamic pressure. He introduced into fluid dynamics the *Prandtl number* (1910), the ratio of kinematic viscosity and thermal diffusivity, a dimensionless quantity which became widely used in momentum and heat-transfer calculations. To explain turbulent fluxes he devised the *Prandtl mixing length* (1925), an average distance of air parcel turbulent movement toward a reference height. Together with the British aeronautical engineer Hermann GLAUERT he worked out the *Prandtl-Glauert rule* (1928) for subsonic airflow to describe compressibility effects of air at high speeds. The principle of his *Prandtl wind tunnel* or Göttingen-type wind tunnel (1908), a continuous-flow closed-circuit wind tunnel, was taken up by Jakob ACKERET for the construction of the first Swiss wind tunnel at ETHZ. In addition, he devised the soap-film analogy for the torsion of noncircular sections and wrote on the theory of plasticity and of meteorology.

PRANDTL received many honors and medals, such as the Daniel Guggenheim Gold Medal of the Daniel Guggenheim Fund for the Promotion of Aeronautics, the German National Prize for Art and Science, the Golden Medal of the Royal Aeronautical Society, the Lilienthal Medal of the Wissenschaftliche Gesellschaft für Luftfahrt (WGL), and the Grashof Medal of the Verein deutscher Ingenieure (VDI). His most prominent students included Jakob ACKERET, Albert BETZ, Adolf BUSEMANN, and Theodore VON KÁRMÁN. Numerous national and foreign universities honored him with a honorary doctorate. PRANDTL was a member or honorary member of a number of national and foreign societies devoted to science, engineering, and culture.

Together with Richard VON MISES, an Austrian applied mathematician, he founded in 1922 GAMM, the Gesellschaft für angewandte Mathematik und Mechanik (Society for Applied Mathematics and Mechanics). The annual *Ludwig-Prandtl-Gedächtnis-Vorlesung* (Ludwig Prandtl Memorial Lecture) of the Deutsche Gesellschaft für Luft- und Raumfahrt (German Society for Air and Space Travel) is hosted by GAMM. The *Ludwig-Prandtl-Ring* is the highest distinction awarded by the Deutsche Gesellschaft für Luft- und Raumfahrt Lilienthal-Oberth e.V. for outstanding achievements in aeronautical science and all of its disciplines.

A crater on the far side of the Moon is named for him.

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http://www.seas.ucla.edu/jht/pioneers/pioneers.html.

PICTURE. Courtesy Archiv der Max-Planck-Gesellschaft (MPG), Berlin-Dahlem, Germany.

NOTE. PRANDTL's written legacy, such as his voluminous correspondence, are kept at the Archiv der MPG; http://www.archiv-berlin.mpg.de.

Rankine, William John Macquorn (1820–1872)

▪ Scottish civil engineer and physicist; copromoter of scientific engineering and cofounder of theoretical thermodynamics and modern shock wave physics

William J.M. RANKINE was born in Edinburgh, the second son of David RANKINE, a rifle brigade lieutenant and civil engineer. Because of his poor health, he was taught mostly privately. He entered the University of Edinburgh (1836), where he studied natural philosophy under James David FORBES, who conducted important research on heat and the movement of glaciers. RANKINE received a gold medal for an essay on the *Undulation Theory of Light* (1836) and a prize for his essay on *Methods of Physical Investigation* (1838). After being introduced to railroad engineering by his father, who had become a superintendent for

the Edinburgh and Dalkeith Railway, he left the university without a degree (1838). He went to Ireland, working there mainly on surveys, harbors, and railroads (1839–1841). He was trained as an engineer under Sir John Benjamin MACNEILL, an engineer for the Dublin & Drogheda Railway. After finishing his apprenticeship he returned to Edinburgh, practiced there civil engineering, and made important contributions to the science of railway locomotion. For example, he delivered a paper to the Institution of Civil Engineers (ICE) in London on the fracture of axes by referring to molecular structure (1843). While engaged on railway problems, he devised a method of setting out curves "by chaining and angles at circumferences combined," which has since been known as the "Rankine method."

In 1848, RANKINE began a series of researches on molecular physics. In his theory of matter, which he called "the hypothesis of molecular vortices," matter was composed of atoms, each comprising an atmosphere consisting of innumerable vortices surrounding a comparatively small nucleus: the absolute temperature of an atom being proportional to the square of the vortical velocity and the quantity of heat in a body being the energy of the molecular vortices. Light and heat were regarded by him as the result of vibrations of the nuclei. He applied his hypothesis of molecular vortices to the theory of heat (1850) and attempted to explain the phenomena of double refraction and elasticity of solid bodies in a similar way.

RANKINE is best known for describing the operational thermodynamic cycle of an ideal engine using steam or another vapor. His *Rankine cycle* is less efficient than the Carnot cycle, but has less practical difficulties and is more economic. After his appointment to chair of civil engineering and mechanics at the University of Glasgow (1855–1872), he spent much of his time on educational activities, developing new analytical techniques such as his "reciprocal diagrams" of frames and forces (1856), which allowed an engineer designer greater scope in studying the stresses in structures. He coined new, enduring terms such as "stress," "strain," and "adiabatic." He published most of his original work on the strength of materials and the theory of structures in his two books *A Manual of Applied Mechanics* (1858) and *A Manual of Civil Engineering* (1862).

After settling permanently in Glasgow, RANKINE became increasingly interested in naval architecture. Together with the shipbuilders James Robert NAPIER, Isaac WATTS, and Frederick K. BARNES he wrote *Shipbuilding, Theoretical and Practical* (1866) with the objective of bringing precision and theory to the British naval industry, which was largely empirical. Independently of William FROUDE, he worked out a possible theory of sea waves of finite height (or displacement) on the surface of deep water (1862). Recognizing that the action of a ship propeller is based on the acceleration of water masses swept by the propeller blades, he derived a momentum theory of the propeller (1865).

In August 1869, three years before his death, he first reported on the thermodynamic state of a "wave of finite longitudinal disturbance," assuming that the abrupt thermodynamic change from upstream to downstream – the term *shock front* had not yet been coined – is not isentropic, but rather a region of dissipation; *i.e.*, the fluid is thermally conductive but nonviscous. He derived the equations for continuity, momentum, and energy. Eight years later, the French physicist Pierre-Henri HUGONIOT, apparently unaware of RANKINE's work, derived the same equations, today termed the *Rankine-Hugoniot equations*. RANKINE also worked as a consultant engineer, and together with Stevenson MACADAM, a lecturer in chemistry at the University of Edinburgh, he investigated the accident at the Tradeston Flour-Mills in Glasgow, reflecting on possible causes of flour-dust explosions (1872).

RANKINE published more than 150 papers and wrote 4 books. He was a Fellow of the Royal Society of Edinburgh (from 1849) and the Royal Society of London (from 1853), and was president of the Scottish Institution of Engineers (1858). He received many honors and was awarded the Gold Medal of the Institution of Engineers in Scotland for his contributions to thermodynamics and engineering. Trinity College, Dublin, conferred on him the degree of LL.D. (1857). James C. MAXWELL, promoting substantially the evolution of the kinetic theory of gases, placed RANKINE alongside William THOMSON (from 1892 Lord KELVIN) and Rudolf J.E. CLAUSIUS as one of the main founders of theoretical thermodynamics.

RANKINE's scientific findings also form the foundation of modern soil mechanics. The prestigious *Rankine Lectures*, established by the British Geotechnical Association, have been given annually since 1961 at Imperial College, London, by eminent contributors to geotechnical engineering. They are subsequently published as papers by The Institution of Civil Engineers in the British journal *Géotechnique*.

In fluid dynamics the *Rankine vortex* is an idealized vortex in unbounded fluid with uniform vorticity inside a circular patch and zero vorticity outside. The *Rankine body* consists of a source and a sink. RANKINE is best known for describing the operational thermodynamic cycle of an ideal engine using steam or another vapor. This *Rankine cycle* is less efficient than the Carnot cycle, but has less practical difficulties and is more economic.

Astronomers named a crater on the near side of the Moon after him.

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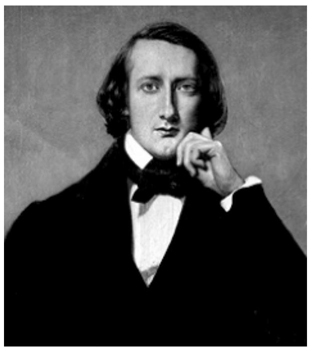
PICTURE. Courtesy Deutsches Museum, Munich, Germany.

NOTE. For collection and biographical history of W.J.M. RANKINE *see* Glasgow University Archive Services; NAHSTE Project; http://www.nahste.ac.uk/cgi-bin/view_isad.pl?id=GB-0248-DC-320&view=basic.

RAYLEIGH J.W. STRUTT, Lord (1842–1919) →STRUTT, John William

REGNAULT, Henri Victor (1810–1878)

▪ French chemist and physicist



Henri V. REGNAULT was born in Aix-la-Chapelle (now Aachen, Germany) to André-Privat REGNAULT, a captain in the Corps des Ingénieurs Géographes Militaires of Napoleon's Army. He lost both his parents when he was only 8 years old. Working first in a textile establishment in Paris, he graduated from the Ecole Polytechnique (1830–1832) and continued his studies in Paris at the Ecole des Mines (1832–1834). After short periods of research under Justus VON LIEBIG at Gießen and Jean-Baptiste BOUSSINGAULT at Lyon, REGNAULT returned to the Ecole Polytechnique. Working there first as an assistant (1836–1840) to Joseph-Louis GAY-LUSSAC, he succeeded him later as chair of chemistry (1840). During this period he conducted most of his famous experimental work in organic chemistry, such as on the halogen and other derivatives of unsaturated hydrocarbons, and in the process discovered vinyl chloride, dichlorethylene, trichlorethylene, and carbon tetrachloride. Shortly afterwards, he succeeded Pierre L. DULONG, a French chemist and physicist, as chair of physics at the Collège de France (1841) in Paris, a position he held until his retirement (1872). His renowned textbook *Cours élémentaire de chimie*

(1847) soon became a classic and was translated into various languages.

Appointed by the minister of public works to redetermine all the physical constants involved in the design and operation of steam engines, REGNAULT produced the first classic work on the properties of steam, which was subsidized by the French government, and the findings were published in 1847, 1862, and 1870. His work was the standard up to the early 20th century.

REGNAULT performed a long series of very careful measurements of the specific heats of many gases, liquids, and solids and also investigated the expansion of gases and devised new instruments. When he became director of the famous porcelain manufactory at Sèvres, he lived and continued his research there in his private laboratory, but all his results and instruments were destroyed during the Franco-German War (1870–1871) in which his son Henri was also killed. REGNAULT never recovered from the double blow, and although he lived until 1878, his scientific labors ended in 1872.

REGNAULT's contributions to shock waves were barely recognized by either his contemporaries or modern shock physicists. Almost 10 years prior to Ernst MACH and Jan SOMMER at Charles University in Prague he first proved by accurate measurements in long pipeline systems that the velocity of sound – in his experiments a blast wave originated by a pistol or the sudden opening of a high-pressure gas reservoir – decreases with the diameter and, therefore, with the intensity, tending to a limit for very feeble sounds. His motivation for turning to acoustics was to precisely determine the mechanical equivalent of heat using the ratio of specific heats, $\gamma = c_p/c_v$. To determine γ he applied POISSON's formula $\gamma = a^2\rho/p$ and measured the sound velocity a in a test substance at given pressure p and density ρ.

The Royal Society of London honored his contributions to organic chemistry and thermodynamics by awarding him the Rumford Medal (1848) and the Copley Medal (1869), respectively. He was elected member of the chemical section of the Berlin and St. Petersburg Academies and member of the French Academy of Sciences (1840) and was a foreign member of the Royal Society of London. In 1863, he was made Commander of the Legion of Honor.

Astronomers named a crater on the near side of the Moon after him.

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PICTURE. Courtesy Collections Ecole Polytechnique, Paris, France.

RIEMANN, Georg Friedrich Bernhard (1826–1866)

▪ German mathematician and physicist

G.F. Bernhard RIEMANN was born in Breselenz, a village approx. 45 km west of Wittenberge, Lower Saxony. His father was Friedrich Bernhard RIEMANN, a Protestant minister. Before entering secondary school he was mostly educated by his father and enjoyed learning since early childhood. After attending the lyceum in Hannover and the Johanneum in Lüneburg (1840–1846) he began to study theology and philology at Göttingen University, but the lectures of the fa-

mous mathematician Carl Friedrich GAUSS influenced him to dedicate himself wholly to mathematics (1846–1847). He continued his education at the University of Berlin under the German mathematician Carl G.J. JACOBI (1847–1849), a codiscoverer of elliptic functions and important contributor to the theory of partial differential equations of the first order with applications to dynamic problems. Upon his return to Göttingen he attended courses in physics given by the famous experimental physicist Wilhelm E. WEBER. In his Ph.D. thesis (1851), supervised by GAUSS, he investigated the geometry of "Riemann surfaces." After preparing his *Habilitationsschrift* (habilitation thesis) on trigonometric series expansion of an arbitrary function, in which he also gave a historical review of this problem, he became in 1853 *Privatdozent* (university lecturer). In addition, he worked as an assistant, probably unpaid, to the mathematician Heinrich M. WEBER, who doubtless inspired him to tackle physical problems mathematically. In 1857, RIEMANN became assistant professor and in 1859 was appointed chair of mathematics at Göttingen University. A few days later he was elected to the Berlin Academy of Sciences.

He gave his first course on partial differential equations with applications to physics entitled *Die Theorie der Integration der partiellen Differentialgleichungen nebst Anwendungen derselben auf verschiedene Probleme der Physik* (1854–1855), a subject on which he deepened his understanding in the following years (1860–1864). In 1859, he published his famous paper on plane sound waves of finite amplitude and purely mathematically discovered the phenomenon of a discontinuous wave structure, which he termed *Verdichtungsstoß* ("condensation shock"). RIEMANN's main motivation to treat this subject was without question the application of linear partial differential equations to problems of applied acoustics. In his introduction he mentioned that Hermann VON HELMHOLTZ, addressing the problem of the origin of combination tones at high sound levels, recommended integrating the differential equations by taking into account also pressure terms of higher order. It appears that RIEMANN's interest in acoustics continued in the following years, and in the last months of his life he wrote a long article on the mechanism of hearing that, being in opposition to VON HELMHOLTZ's theory, was published posthumously (1867). It is interesting here to note that this article contained no mathematics and is a pure physiological-physical description of hearing.

Also in 1859, he reported to the Berlin Academy of Sciences on his most recent research. In his report entitled (in translation) *On the Number of Primes Less Than a Given Magnitude*, he extended the zeta function to complex values and made the famous conjecture about how prime numbers were distributed among other numbers, now known as the "Riemann hypothesis," which is of fundamental importance in number theory. It remains today one of the most important of the unsolved problems of mathematics. In 2001, the Clay Mathematics Institute (CMI) in Cambridge, MA offered a $1 million prize to the first person to prove or disprove the Riemann hypothesis.

In the period 1862–1866, he suffered several attacks of pleurisy, and, despite attempts to recover in Italy, where he spent two winters in Pisa, he died in 1866 at Selasca, a town in Piedmont near Intra on the Lago Maggiore, at the early age of 39. Despite his short life, RIEMANN's contributions to mathematical physics are huge and encompass mechanics, gravity, acoustics, electricity, and magnetism. He was a corresponding member of the Berlin Academy of Sciences (from 1859) and a member of the Göttingen Academy of Sciences (from 1860).

Karl HATTENDORFF, one of RIEMANN's former auditors, edited RIEMANN's lecturers after his death in a book entitled *Partielle Differentialgleichungen und deren Anwendung auf physikalische Fragen: Vorlesungen von Bernhard RIEMANN* (1869). Seven years later, Heinrich M. WEBER, a mathematics professor at the University of Königsberg who was interested in the same subject, published the textbook *Die partiellen Differentialgleichungen der mathematischen Physik, nach RIEMANN's Vorlesungen* (1876), in which he followed RIEMANN's concept. WEBER's book, in which he also treated shock waves, went through six editions and became a classic of mathematics.

Among mathematicians RIEMANN became widely known for devising *Riemann surfaces* and *Riemannian geometry*. Among fluid dynamicists his *Riemann method* for solving linear hyperbolic second-order partial differential equations using the *Riemann function* proved most useful. The *Riemann invariants* are very helpful for analyzing linear solutions of the wave equation by determining "simple waves" as building blocks for constructing more complex solutions.

Astronomers named a crater on the near side of the Moon and a minor planet (asteroid 4167 RIEMANN) after him.

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PICTURE. After a copper engraving by A. WEGER. From (R. NARASIMHAN, ed.) *Bernhard RIEMANN's gesammelte mathematische Werke, wissenschaftlicher Nachlaß und Nachträge.* Springer, Berlin (1990).

ROBINS, Benjamin (1707–1751)

▪ British mathematician and military engineer; founder of scientific ballistics

Benjamin ROBINS was born in Bath, Somerset. His father, John ROBINS, was a tailor, and his parents were Quakers. Originally trained as a teacher, he soon left that profession and started as a mathematician but only gave private lessons. He was elected to the Royal Society of London (1727) and got involved in mechanics and various projects of civil engineering. In addition, he began to study gunnery and fortification. With his book *New Principles of Gunnery* (1742) he became an internationally reputed ballistician. Translated into German and comprehensively annotated by Leonard EULER (1745), the book laid the groundwork for modern gun theory and practical ordnance (field artillery). At the request of the British Admiralty, EULER's work was translated into English by the English mathematician Hugh BROWN, who supplemented it with his own annotations (1777). The French Charles LE ROY translated ROBINS' book for the Paris Académie des Sciences (1751).

ROBINS' theory of fired gunpowder assumed that all the powder of which a charge consists is not only set on fire, but that it is actually consumed and "converted into an *elastic fluid* before the bullet is sensibly moved from its place." To measure the muzzle velocity of projectiles, he first applied the ballistic pendulum (1740), which was already suggested earlier by Jacques CASSINI (1707). His pendulum was suspended from a tripod, and the bullet was shot into a wooden block screwed to the pendulum. It enabled ballisticians for the first time to also measure the influence of drag on projectile velocity and geometry by positioning the ballistic pendulum at different distances from the muzzle. He discovered that the force of aerodynamic drag could be as high as 120 times the projectile's weight. Since ROBINS already noticed a significant increase in drag upon approaching the sound barrier and even studied supersonic projectile velocities up to $M = 1.5$, his investigations can be regarded as the birth of scientific supersonic aerodynamics.

ROBINS, also studying the lateral deflection of high-speed projectiles by setting up a series of evenly spaced paper curtains, observed that a musket ball in flight is enormously deflected and identified the spin of the ball as the cause of this deflection. He also investigated pressures on projectiles inside a gun barrel and the shape of actual – as opposed to ideal – trajectories (1742). He predicted the superiority of rifled cannon; however, the first comprehensive experiments on realizing this technically demanding concept eventually changing warfare did not start until in the 1830s in Europe and the United States. In the famous *vis visa* controversy, initiated in 1686 by the German natural philosopher Gottfried Wilhelm LEIBNIZ, ROBINS took part in a polemic manner attacking Sir NEWTON's enemies who, besides LEIBNIZ, included the Italian mathematician Giovanni POLENI, the Swiss mathematicians Daniel and Johann BERNOULLI, and others.

ROBINS' last work consisted of investigations on rockets for the purpose of military signaling. Appointed Engineer General by London's East India Company he went to Madras, India to repair and improve the forts of the Company.

Starting at Fort St. David in Cuddalore, India in 1750, he died there of a fever only a year later.

From the Royal Society of London ROBINS received the Copley Medal (1746) for his contributions to ballistics, particularly for his studies on aerodynamic drag at high speeds. Many of his writings were published posthumously by his friend James WILSON in the *Mathematical Tracts* (1761). The numerous secondary literature recently published on ROBINS' life and work well illustrates the curiosity of modern ballisticians about his unique contributions. In the 1830s, ROBINS' ballistic pendulum was significantly improved by the Commission des principes du tir, a French ballistic commission that consisted of the French mathematicians Isidore DIDION, Arthur MORIN, and Guillaume PIOBERT.

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NOTE. There exists no picture of ROBINS; private communication from Prof. emer. William JOHNSON, F.R.S., Cambridge, U.K.

RODMAN, Thomas Jackson (1815–1871)

▪ U.S. brigadier-general, military engineer, and inventor

Thomas J. RODMAN was born in Salem, IN. His father was a farmer. He graduated from the ordnance department of the U.S. Military Academy at West Point, NY (1841) and was the 1065th graduate of the Academy. Assigned to the U.S. Ordnance Department, he was assigned to various arsenals. Serving at Alleghany Arsenal, PA, until 1848, he carried out experiments on war materiel and summarized the results in numerous Alleghany Arsenal reports (1857–1858). His fifth report contains the first description of his cutter gauge, the so-called "Rodman gauge" (1857). His indenting apparatus is a pressure gauge consisting of a piston working in a hole bored into the wall of a gun and acting on an indenting tool. Measurement of the depth of the indentations indicate the

relative pressure along the tube. In a simple manner it allows one to measure the absolute pressure of fired gunpowder or gas in the bore of a gun. RODMAN's invention was immediately resumed by various European countries. However, in 1894 the British ballistician and gun expert Sir Andrew NOBLE first demonstrated that the maximum pressures in gun barrels derived by RODMAN from his indentation gauge were far too high (1894).

RODMAN served as a superintendent of Watertown Arsenal, MA, where he spent the Civil War producing cannon for the Union. In particular, he devised the method of casting guns on a hollow core, the metal being cooled by a stream of water running through the inside – a technique that showed greater power of resistance than those that involved casting in the usual way; *i.e.*, in one piece, and afterwards bored out. The first of his famous so-called "15-in. smooth-bore Rodman gun," a new form of columbiad intended primarily for sea-coast defense, was successfully tested in March 1861. Three years later he even increased the caliber to 20-in., which required a four-piece mold taking 160,000 lb. of molten iron. His new 20-in. smooth-bore cannon, then the largest in the world, brought him into prominence; it was capable of firing a 1,080-lb. projectile at a maximum range of 4.5 miles. However, it was too big and because of technical problems never used in practice.

For proper operation of these huge guns he proposed his "mammoth powder," later called "Rodman powder" (1860), a large-grained, progressively-burning powder that became a useful propellant because it burned slowly. Thus, a high velocity would be given to a shot without subjecting the gun to excessive strain. His mammoth powder was adopted by the U.S. government, and soon after by Russia, England, and Prussia.

In the Civil War he was appointed brigadier-general (1861). Four years before his death, he was promoted to the rank of lieutenant-colonel (1867). Worn down by his many activities and responsibilities, he died prematurely at the age of 56 at Rock Island Arsenal, IL. Besides Charles E. MUNROE, he is certainly the most prominent figure of 19th-century American research on explosives and propellants and their use for military purposes.

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PICTURE. Courtesy John L. CARNPROBST, Pittsburgh, PA.

RUSSELL, John Scotch (1808–1882)

▪ Scottish engineer and naval architect; father of the solitary wave (soliton) and irregular wave reflection

John S. RUSSELL was born in Parkhead near Glasgow. He was the eldest son of Rev. David RUSSELL, a Scottish minister. Destined by his father for the Church, he showed a great love for mechanics at a very early age and eventually prevailed upon his father to allow him to study science and practical mechanics. He studied at the University of Glasgow, where he also graduated with an M.A. (1825). He moved to Edinburgh, where the University of Edinburgh offered him a temporary appointment as professor of natural philosophy (1832–1833), which became vacant by the death of Sir John LESLIE, a Scottish physicist and mathematician.

In the following years, he carried out investigations for the Scotch Canal Company on the practicability of steam navigation on inland waterways. These studies sparked his interest in the effects of water waves on hulls. About this time, he commenced his well-known researches on the nature of waves and the resistance of fluids to the motion of floating

bodies (1834). RUSSELL discovered and studied experimentally the "wave of translation," which he also called "great solitary wave" – a wave consisting of a single hump of constant shape and constant speed. His first paper, submitted to the British Association for the Advancement of Science (BAAS), showed how the wave of translation could be used to reduce the resistance of barges moving fast in a restricted waterway (1835). He spent a major portion of his professional life carrying out experiments to determine the properties of the solitary wave. While investigating unsteady, non-uniform, open-channel flow, he discovered a new type of irregular reflection, in appearance very similar to the Mach effect in gas dynamics, and presented his numerous experimental results to the BAAS (1834–1835, 1837). For these wave studies the Royal Society of Edinburgh awarded him the Gold Medal.

As an outcome of his study on water waves he proposed his "wave-line design," a reverse-curve form of the bow in order to produce a solitary wave of the smallest possible amplitude – thus reducing the water resistance of the hull. The first vessel based on this wave line system, the 18.3-m-long SS *Wave*, was built in 1835, followed by three longer experimental vessels of differing forms to test his theory. Having moved to London (1844), he became a well-known shipbuilder on the Thames and constructed a number of ships on his principle such as the HMS *Warrior* (1860), the world's first wholly ironclad battleship. He believed that his wave-line theory could also be extended to reduce the resistance of ships in the open sea based upon the idea of pushing the water aside with minimum loss of energy. Although ships of his design were faster and could be operated more economically, he was unable to derive a sound mathematical theory of ship design. Together with the British naval engineer Isambard K. BRUNEL he cooperated on the design of big steamers, one of which was the enormous 211-m, 18,914-ton SS *Great Eastern*, RUSSELL being responsible for designing the hull form and paddle engines as well as for the actual building (1851–1858). It was the first ship to be built with a double iron hull and had sufficient tonnage to store the first transatlantic cable (1866).

Besides naval construction, RUSSELL practiced in other fields of engineering: for example, he wrote an article on steam engines in the *Encyclopædia Britannica* (7th edn., 1842), constructed a steam-ferry for carrying railways across the Lake of Constance (1868), built a steam coach for common roads, and designed the great dome of the Great Exhibition of Vienna (1873), whose clear span was about 110 m.

In addition, he took an active part in the foundation of the Royal Institution of Naval Architects and in the management of the Royal Society for the Encouragement of Arts, Manufactures and Commerce (RSA). He wrote many professional and scientific papers, which he read before various institutions and societies.

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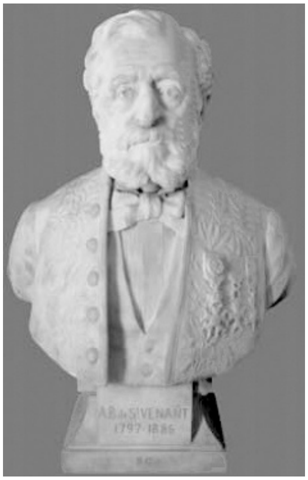
PICTURE. Courtesy Science Museum Library, London, U.K.

SAINT-VENANT, Adhémar Jean Claude, Barré DE SAINT-VENANT (1797–1886)

▪ French mathematician and civil engineer

Adhémar J.C. SAINT-VENANT was born at the castle of Fortoiseau (Dépt. Seine-et-Marne). His father was a distinguished agronomist and a former officer. He entered the Ecole Polytechnique in 1813. However, because of his political activities he was not permitted to continue his study.



Working already early in his career very successfully as an assistant in the Service des Poudres et Salpêtres (1814–1823), he was soon permitted by the government to enter the Service des Ponts et Chaussées without a final examination. There he finished his study at the school of this organization (1825). Already in 1834 he presented two remarkable papers to the Paris Academy on theoretical mechanics and fluid dynamics, which were published posthumously (1888). After working for some time on various French channels, he devoted himself to teaching on the subject of the strength of materials at the Ecole des Ponts et Chaussées (1837–1842). Together with Pierre L. WANTZEL (1814–1848), a French road engineer, he studied the exhaust of gases from nozzles and provided fundamental formula relating pressure and speed in compressible flow (1839). His *Mémoires d'hydraulique agricole* earned him a medal of the Society of Agriculture (1849) and a position as a professor at the newly founded Institute of Agriculture at Versailles (1850).

In 1852, he retired from his duties as Chief Engineer of the Paris constructions authority in order to fully devote himself to science, in particular to mechanics with an emphasis on the elasticity and rigidity of solids. Investigating the bending of rectangular beams both experimentally and theoretically, he stated that (1) the cross sections of a beam remain plane during the deformation and (2) the longitudinal fibers of a beam do not press upon but rather glide along each other [French *glissement*], being in a state of tension or compression. In 1855, he published a paper titled *Mémoire sur la torsion des prismes, avec des considérations sur leur flexion, ainsi que sur l'équilibre intérieur des solides élastiques en général* ("Memoir on the torsion of prisms, with considerations on their deflection, as well as on the internal equilibrium of elastic solids in general"), where he presented a new engineering method of calculating stresses in structures, which he called "la méthode mixte" and which others (*e.g.*, CLÉBSCH, TAIT, KELVIN, KIRCHHOFF) called the "de Saint-Venant problem" – today better known as the "Saint-Venant principle." This memoir, together with an article on the bending of bars, published in the following year in the *Journal de mathématiques pures et appliquées*, constituted the most complete and exact solution to the problem of deformation hitherto known. Treating the head-on collision of long, cylindrical bars (1862–1867), which was later applied in the Hopkinson pressure bar and derived devices for measuring mechanical properties of materials, he pointed out that elastic waves were generated during collisions that, even in the case of an ideal-elastic material, absorb kinetic energy, a fact that was later confirmed experimentally by Carl W. RAMSAUER (1909). In connection with the application of nonuniform load distribution at the bar end of Hopkinson devices and their proper measurement using strain gauges bonded to the bar outside, an investigation was made in the 1950s into whether the Saint-Venant principle could also be extended to dynamic "nonequilibrium" loading problems.

DE SAINT-VENANT published about 160 papers, notes, and memoirs covering geometry, mathematics, mechanics, hydrostatics, hydrodynamics, and agriculture. His significant contributions to the mechanics of solid bodies made him soon internationally renowned, and after the death of Gaspar G. DE CORIOLIS he was elected head of the mechanics section of the Paris Academy of Sciences (1843). He was also a member of the Institut de France, of the Royal Society of Göttingen, and of the Academies of Manchester, Louvain, and Brussels.

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PICTURE. Courtesy J. BARANDE, Bibliothèque de l'Ecole Polytechnique, Paris, France.

SALCHER, Peter (1848–1928)

▪ Austrian physicist

Peter SALCHER was born in Kreuzen-Ebene, a small village in Carintia, Austro-Hungarian Empire (now southern Austria). His father, Peter SALCHER III, was a school teacher, mayor, farmer, and innkeeper. He attended the gymnasium in Klagenfurt (1861–1868) and studied natural philosophy at the University of Graz, where he graduated with a *Dr. phil.* (1872). After a short period of teaching at various gymnasia in Graz and Triest (1872–1875), he was appointed full professor of physics and mechanics (1875–1909) at the Austro-Hungarian Imperial Royal Naval Academy in Fiume (now Rijeka, Croatia), where he managed from 1880 the local meteorological station. Being a skillful experimenter and inventor of scientific instruments, SALCHER became internationally famous for his supersonic ballistic experiments, which he

performed at the Naval Academy in Fiume (1886–1889). He corresponded with the Austrian physicist Ernst MACH, spiritual father and originator of this ballistic study, on the progress of his work, also contributing many ideas of his own. Together with John WHITEHEAD, son of the British torpedo expert and manufacturer Robert WHITEHEAD, he visualized free air jets generated by discharging a high-pressure reservoir through a small opening. They first noticed a characteristic oblique pattern of stationary waves in the jet, now known as "shock diamonds" – a curious irregular interaction phenomenon of shock waves which creates a sequence of Mach disks in the jet and occurs anytime a flow exits a nozzle at supersonic speeds. These experiments, no less important than the discovery of the head wave phenomenon, were later resumed in Göttingen by Ludwig PRANDTL and Theodor MEYER, stimulating the understanding of supersonic flow both inside and outside of Laval nozzles.

SALCHER published numerous papers dealing with physical, meteorological, and fluid dynamic observations and wrote several books on mechanics, physics, oceanography, meteorology, and the history of the Austro-Hungarian Navy. These papers were primarily intended to serve the education of K.u.K. naval cadets. He received various high-ranking Austrian awards, such as the Knight's Cross of the Franz Joseph Order and the *Signum laudis* (an Austrian medal of honor). He was a corresponding member of the Austrian and Australian Academies of Sciences, and a member of the French Physical Society.

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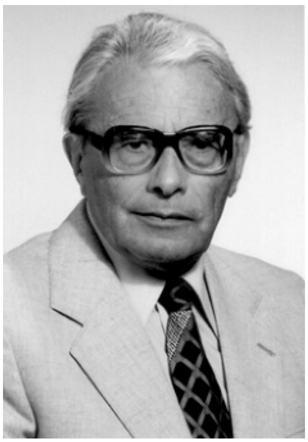
PICTURE. Courtesy Dr. Günther SALCHER, Hermagor, Austria.

NOTE. While photographing supersonic projectiles (1886–1889), SALCHER continuously reported to E. MACH on the progress of his investigations in 140 letters. MACH's response letters, in 1993 rediscovered by the author, are kept by G. SALCHER at Hermagor. The Max-Planck-Institut (MPI) für Wissenschaftsgeschichte at Berlin plans to edit and annotate this correspondence.

SCHALL, Rudi Joachim (1913–2002)

▪ German detonation and shock wave physicist



Rudi J. SCHALL was born in Berlin-Zehlendorf to Wilhelm SCHALL, a high-school teacher. After attending the secondary school in Zehlendorf, he entered the Friedrich-Wilhelms-Universität (since 1945 Humboldt-Universität) in Berlin and began to study mathematics, physics, and chemistry (1931). After his diploma he took the degree of *Dr. phil.* (1937) with a work on acoustics entitled *Symmetrisch geschaltete kapazitive Mikrophone* ("Symmetrically Connected Capacitive Microphones"); his thesis adviser was Prof. Arthur Rudolph WEHNELT, renowned for his invention of the "Wehnelt cylinder." SCHALL continued to work at the Friedrich-Wilhelms-Universität as an assistant to Prof. Erich SCHUMANN, an acoustician and military physicist who also headed the research division of the Heereswaffenamt (Army Ordnance Office) and was Deputy of Detonation Physics in the Reichswehr Ministry (1942–1945). Asked by SCHUMANN to explore the actual state of the art of nonlinear acoustics, SCHALL got involved in explosives and detonation physics. He performed military research for the army and became an expert on explosives and detonation.

In 1946, SCHALL joined Prof. Hubert SCHARDIN at the newly founded Laboratoire de Recherches Techniques de Saint-Louis (LRSL), which, by a German-French treaty signed in 1959, was transformed into a binational research institute, named the *Institut Franco-Allemand de Recherches de Saint-Louis* or *Deutsch-Französisches Forschungsinstitut Saint-Louis* (ISL). There he continued his research in detonation physics and did pioneering work on hollow charges, shock waves, detonation waves, and high-speed diagnostics. SCHALL's contributions are manifold. (1) In 1950, he was the first to obtain a flash X-ray diffraction pattern of a shock-loaded crystal within ultrashort times, a subject that was taken up again in the United States at LLNL not until the late 1960s. (2) In 1950, he also determined the Hugoniot curves of some liquids and solids up to very high pressures using an explosive compression technique and flash radiography. With this combined method he measured the detonation pressure of explosives. (3) Based upon the first systematic series of flash radiographs of jet formation in shaped charges, which he obtained in cooperation with Gustav THOMER, a German physicist at ISL, he derived a theory of twist-stabilized hollow charges. Later, in cooperation with the Schlumberger Company, he also explored civil applications of short hollow charges for use in the petroleum industry. (4) Based on the hydrodynamic theory of detonation and on the assumption of an incomplete decomposition of solid explosives, he concluded that it should be possible to produce stable low-velocity detonations over a fairly wide range of velocities. (5) He studied the initiation process of secondary explosives by a spark discharge, which would allow a safer handling of explosives, particularly in mining applications. (6) He also took a continuous interest in the progress of modern high-speed diagnostic methods, initiated their further development at ISL, and reviewed modern achievements at international congresses.

In the period 1962–1969, SCHALL worked for NATO in Paris and Brussels, serving there as deputy general secretary of the Division of Scientific Affairs. After his return to ISL, he was appointed German Director, a position which he held until his retirement (1969–1979). Thereafter, he directed the Carl-Cranz-Gesellschaft (CCG) in Weil am Rhein, a society devoted to post-academic training in engineering sciences. He published more than 70 papers in the open literature, which brought him renown beyond the military research community. At the International Congresses on High-Speed Photography he was National Delegate of the Federal Re-

public of Germany (1968–1980). In 1980, he received the Photo-Sonics Award of the American Society of Motion Pictures and Television Engineers (SMPTE).

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PICTURE. Courtesy ISL, Saint-Louis, France.

SCHARDIN, Hubert (1902–1965)

▪ German physicist, gas dynamicist and ballistician, father of numerous color schlieren methods

Hubert SCHARDIN was born in Plassow, Pomerania (now Plaszewo, Poland). He was the eldest son of Reinhold SCHARDIN, a school teacher. He studied physics at the Technische Hochschule Berlin-Charlottenburg (TH Berlin) and the University of Munich (1922–1928). After graduating in technical physics (1926), he became assistant of Geheimrat Prof. Carl

CRANZ at the Institut für Technische Physik of the TH Berlin, which was essentially the ballistic laboratory of the former Military Academy. Under CRANZ's supervision he worked on the theoretical foundations of the Toepler schlieren method and its applications, which earned him the Ph.D. (1934). CRANZ and SCHARDIN went together to Nanking to establish the first ballistic research institute in China (1934–1936). Thereafter, SCHARDIN became director (1936) of the Department of Technical Physics and Ballistics at the Technische Akademie der Luftwaffe (TAL) (Air Force Technical Academy) in Berlin-Gatow. In addition, he served as assistant professor (1936) and full professor (1941) at the TH Berlin.

At the end of World War II, his ballistic department at TAL was evacuated to southern Germany and after the war transferred by the French military to the Alsatian town of Saint-Louis. He became scientific director of the newly founded Laboratoire de Recherches Techniques de Saint-Louis. From 1945 SCHARDIN and the French Ingénieur-Général Robert CASSAGNOU expanded military research and in 1959 established the binational Institut Franco-Allemand de Recherches de Saint-Louis or Deutsch-Französisches Forschungsinstitut Saint-Louis (ISL). SCHARDIN, who became honorary professor at the German Universities of Freiburg (1947) and Cologne (1965), also established two departments of applied physics in Weil am Rhein and at the University of Freiburg (1949), which, ten years later, merged into the Ernst-Mach-Institut (EMI), a subsidiary research institute of the Fraunhofer-Gesellschaft (FhG) with headquarters in Munich.

In the very fruitful period of cooperation with CRANZ (1926–1936), SCHARDIN tackled many technical problems of his time, which resulted in numerous milestone achievements. (1) He provided a solid theoretical background for schlieren imaging and applied it to a broad range of scientific pursuits. (2) In high-speed photography, he applied new spark light sources and the Kerr-effect for chronography. His ultrahigh-speed framing camera, which he developed in cooperation with CRANZ – the so-called "Cranz-Schardin multiple spark camera" [Germ. *Cranz-Schardin Mehrfach-Funkenkamera*] – earned him a Gold Medal at the Paris World Exhibition (1937). (3) He refined some main optical visualization techniques in gas dynamics and extended the theory of Mach-Zehnder interferometry and its applications. (4) He studied the ballistic drag of projectiles, both inside the barrel and during flight. (5) He extended the shock-tube theory and applied it to a number of practical examples. (6) He also worked on the fundamentals and applications of detonation physics, particularly on hollow charges. (7) After the war he mainly worked on problems of nonstationary gas dynamics. He theoretically and experimentally studied the nature of spherical blast waves generated in chemical explosions and blast effects on architectural structures. (8) Phenomena observed during interactions of blast waves with window panes also stimulated his interest in the nature of fracture mechanics. He was the first to use high-speed cinematography to resolve the fracture mechanism in brittle materials such as glass.

SCHARDIN presided over the Schutzkommission, a committee for the protection of civil buildings established by the German Ministry of the Interior, was cofounder and member of the executive board of the Deutsche Gesellschaft für Wehrtechnik (German Society for Military Technology), and initiator of the Carl-Cranz-Gesellschaft (CCG), then primarily an institution for scientific training of young military talents. He was one of the first and most enthusiastic promoters of founding an International Congress on High-Speed Photography; the first one was held in Washington, DC (1952).

The *Hubert Schardin Medal* award, instituted in his honor by the 8th International Congress on High-Speed Photography (1968), recognize achievements in high-speed diagnostics and in their many applications, both in fundamental research and in technical engineering. This award is particularly aimed at encouraging young scientists for performing outstanding work in this field.

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PICTURE. Courtesy Archives of Ernst-Mach-Institut (EMI), Freiburg, Germany.

SCHMIDT, Oswald VON (1889–1945)

▪ Estonian-born German physicist

There is little information about Oswald VON SCHMIDT's life except what can be found in his autobiography attached to his Ph.D. thesis. He was born in Dorpat (at that time a part of Russia, now Tartu, Estonia) to Arved VON SCHMIDT, an attorney. After attending a private gymnasium and the Dorpat State Gymnasium, he studied chemistry and physics (1909–1912) at the University of Dorpat. He graduated from the University of Göttingen in physical chemistry and metallurgy and began to prepare his Ph.D. thesis under the guidance of Prof. Gustav TAMMANN and Prof. Otto WALLACH but was drafted at the beginning of World War I. Thereafter, he continued his studies at the Friedrich-Wilhelms-Universität (since 1945 Humboldt-Universität) in Berlin and took his Ph.D. (1919–1921) under the guidance of Prof. Walther Hermann NERNST, an eminent physical chemist.

Later he investigated the propagation and reflection phenomena of waves at boundaries of different states of matter. Theoretical foundations were already laid by him in the late 1920s and later continued at the Technische Hochschule Berlin by a study group that was financially supported by the Notgemeinschaft der Deutschen Wissenschaft. While employed at the Ballistic Institute of the Technische Akademie der Luftwaffe (TAL), a recently established technical academy of the German Air Force in Berlin-Gatow (1938), he performed his famous photogra-

phy of head wave phenomena at liquid and solid boundaries, the so-called "Schmidt head wave" [Germ. *VON SCHMIDTsche Kopfwelle*]. This pseudo-supersonic wave effect which can be observed both in acoustics and shock wave physics is of great importance

VON SCHMIDT died in Berlin at the end of World War II.

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SCHMIDT, Paul (1898–1976)

▪ German mechanical engineer and inventor

Paul SCHMIDT was born in Hagen, a town in the Ruhr Area, North Rhine-Westphalia. After fighting in World War I, he studied mechanical and electrical engineering at the Universities of Münster, Hannover, and Munich (1919–1924). He became employee (1924) and later partner (1928–1934) of a Munich engineering office that performed consulting on the design of centrifugal pumps. In this period he worked out

his idea of a recurrently operating pulsejet engine for aircraft. He began experiments that were focused on the ignition of combustible mixtures by shock waves and supported by the German Ministry of Transportation. In 1934, he suggested to the Reichsluftfahrtministerium (RML) to apply his invention in the building of a flying bomb.

Based on his favorable results, he received a grant from the RML that allowed him to continue his research on a larger scale. At the outbreak of World War II, his experiments resulted in in the serviceable prototype of a periodically operating pulsejet engine – the so-called "Schmidt tube" [Germ. *Schmidtrohr*]. Erhard MILCH, Hermann GÖRING's deputy and director of air armament, being aware of the potentials of the Schmidt tube engine, approached the engineer Robert LUSSER at the Gerhard Fieseler Werke in Kassel to draw up plans for what later became known as "Vengeance Weapon One" [Germ. "*Vergeltungswaffe Eins*"] or "V1". This induced the RML to put Argus GmbH in Berlin in charge of the final development – the so-called "Argus-Schmidt tube" [Germ. *Argus-Schmidtrohr*]; the project leader was Fritz GOSSLAU. Development of such engines also began in mid-1942 at the secret research facility at Peenemünde-West on the Baltic Sea. The first flights were successfully performed in 1941 with a carrier aircraft and continued in 1943 with a Messerschmitt Me-328, a fighter that was propelled by a twin Argus-Schmidt tube engine. However, the extreme vibrations created by the pulsejets proved highly detrimental to the light airframe.

The pulsejet engine was analyzed in more detail at the Deutsche Versuchsanstalt für Luftfahrtforschung (German Aviation Research Facility) by Adolf BUSEMANN (1936) and at the TH Aachen by Fritz SCHULTZ-GRUNOW (1943). In 1944, its first mass production and application as a flying bomb began. It was also used to warm up jet aircraft engines by directing the jet into the turbine blades. The V1 so impressed the U.S. Army that it planned to build large numbers of first-generation cruise missiles, designated the JB-2 "Loon." It was based on the V1 but incorporated improved guidance systems using airborne and shipborne radars, radio control, and human operators, giving them much greater ac-

curacy. About 1,000 JB-2s had been delivered to the U.S. Army and Navy by the end of World War II.

After the war, the Schmidt tube was applied by the American Helicopter Corporation to drive the rotor blades directly with jets at the blade tips, which eliminated the heavy engine and its gearing to the blades. In France it was used under the name *Escopette* to assist gliders in takeoff. In the 1950s, SCHMIDT came up with the idea of using a multitude of pulsejets in a large spherical arrangement in order to focus the generated pressure waves in the center and to possibly initiate a thermonuclear reaction (Germ. Patent No. 1,016,376).

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PICTURE. Courtesy Mrs. Grete KLIMM, Paul SCHMIDT's daughter, Rummelsberg, Bavaria, Germany.

SCHULTZ-GRUNOW, Fritz Claus (1906–1987)

▪ German mechanical engineer and fluid dynamicist, founder of the Aachen Shock Wave Laboratory

Fritz C. SCHULTZ-GRUNOW was born in Munich. After taking his Abitur at Konstanz, he studied mechanical engineering at the ETH Zurich. He began working as a constructional and experimental engineer at the Escher-Wyss AG in Zurich and the Henschel Co. in Kassel, but then decided to enter research. He went to the Kaiser-Wilhelm-Institut (KWI) für Strömungsforschung in Göttingen and became one of Ludwig PRANDTL's assistants (1935). There he habilitated with a study on the after-effects of turbulence in the cases of locally and temporarily delayed boundary layer flows (1938). He was appointed lecturer in applied mechanics at the University of Göttingen (1939–1941) and subsequently took the prestigious chair of mechanics at the RWTH Aachen, which had been offered to him; in this position he also headed the affiliated Institute of Mechanics (1941–1975). During his directorate he considerably extended the institute's scope of research, including also a newly founded Shock Wave Laboratory, the *Stoßwellenlabor RWTH Aachen* (1956). In addition to his duties as a university teacher he also temporarily directed the Ernst-Mach-Institut at Freiburg (1967–1972).

During this period he worked out a gasdynamic theory of spinning detonation (1973).

In his Göttingen period he worked initially on classical problems of mechanics (theory of shells and fundamentals of modern construction engineering) and on fluid mechanics (turbulence, boundary layer theory, and rheology of lubricating oils). In his Aachen period he dedicated himself to the investigation of specific problems in aeronautics and astronautics, high-temperature engineering, and energy technology (flow, transport and reaction phenomena in hot gases). His Shock Wave Laboratory, the *Stoßwellenlabor der RWTH Aachen*, became widely known for its hypersonic studies on the mechanical and thermal loading of model orbital space vehicles and the Space Shuttle, and the development of various high-speed diagnostic techniques.

Prof. SCHULTZ-GRUNOW supervised more than 50 Ph.D. theses and 5 habilitation theses. His numerous contributions to research and education were acknowledged by the awarding of the honorary doctorate of the University of Stuttgart (1977), the Ludwig-Prandtl-Ring (1979), and the Grand Cross of the Order of Merit of the Federal Republic of Germany (1987). He was a Fellow of the AIAA (from 1957) and a corresponding member of the Institute of Aeronautical Sciences, New York. He edited the proceedings of the GAMM conference *Elektro- und Magnethydrodynamik* (Aachen, Oct. 1967).

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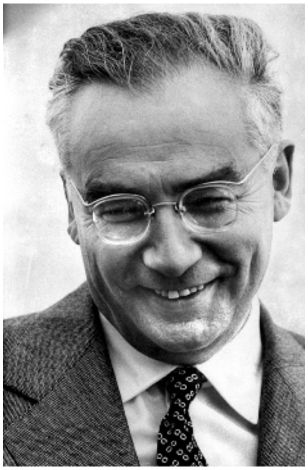
PICTURE. Courtesy Archives of the Ernst-Mach-Institut, Freiburg, Germany.

SEDOV [Russ. *СЕДОВ*], Leonid Ivanovich (1907–1999)

▪ Soviet mathematical physicist and hydrodynamicist

Leonid I. SEDOV was born in Rostov-on-Don, south-west Russia. His father was Ivan Grigorevich SEDOV, a mining



engineer. In 1931, he graduated from the Physical-Mathematical Faculty of Moscow State University [Russ. *МГУ*]. At the Central Aero-Hydrodynamic Institute [Russ. *ЦАГИ*], then the leading Russian institution in fluid dynamics and directed by Prof. Sergey A. CHAPLYGIN, he specialized in mechanics and hydrodynamics and became a staff member (1931–1947). After taking his Ph.D. he was given the title of professor of dynamics at Moscow State University (1937). Concurrently he worked at the Institute of Mathematics of the U.S.S.R. Academy of Sciences (1945) and at the Central Institute of Aircraft Engine Construction [Russ. *ЦИАМ*] (1947–1956).

His numerous contributions to theoretical fluid dynamics and mechanics comprise a wide field, such as (1) a theory of ideal fluidity (1937) that was stimulated by CHAPLYGIN's early research; (2) a thorough treatment of percussion and gliding phenomena, so-called "ricocheting" (1941–1942), then of great practical interest for designers of hydroplanes and in the 1930s also treated by German researchers; (3) an aerodynamic theory of flat airfoils; (4) a method of using ordinary differential equations in order to obtain accurate solutions for gasdynamic equations; (5) a theory of strong explosions, resulting in the so-called "Sedov equation" (1946), which was later confirmed by the first Soviet nuclear weapons test (1949); (6) a phenomenological theory for the construction of a model of continuous media on the basis of variational principles (1965); and (7) a theory of unstabilized gas motion and dispersion of strong shock waves, derived from the theory of similarity and dimensionality. He published about 200 articles, and most of his monographs were also translated into English. Among shock physicists the most renowned books are (in translation) *Similarity and Dimensional Methods in Mechanics* (1951), *Two Dimensional Problems in Hydrodynamics and Aerodynamics* (1965), and *Unsteady Motion of Compressible Media with Blast Waves* (1967).

SEDOV was elected corresponding member of the U.S.S.R. Academy of Sciences (1946) and became Academician (1953). He served as chairman of the Interdepartmental Commission on Interplanetary Communications of the U.S.S.R. Academy of Sciences "to coordinate and direct all work concerned with solving the problem of mastering cosmic space." In the period 1959–1961, he was president of the International Astronautical Federation (IAF). He was awarded the Chaplygin Medal (1946) of the U.S.S.R. Academy of Sciences, won a Stalin Prize (1952), and received the Order of the French Legion of Honor (1952). He also received the first Lomonosov Prize (1954) for his contribution of applying methods of gas dynamics to astrophysical problems and was Hero of Socialist Labor (1967). In 1981, he received, together with the Austrian politician Peter JANKOWITSCH, the Allen D. Emil Memorial Award of the International Astronautical Federation (IAF). In 1993, he received the Nikolai Zhukovsky Prize and the Academy Medal for his outstanding contribution to the development of mechanics.

The second phase (or adiabatic phase) in the lifetime of a supernova remnant, in which the material begins to decelerate and the ejecta of the supernova remnant mix up with the gas that was just shocked by the initial shock wave, is named after him (*Sedov phase*).

Astronomers named a minor planet (asteroid 2785 SEDOV) after him.

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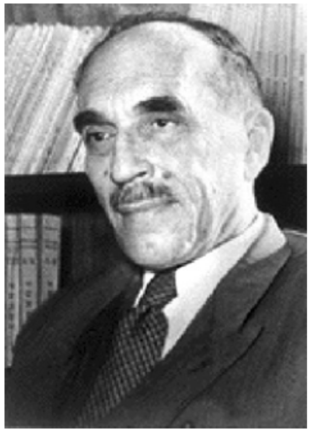
PICTURE. Taken by Howard SOCHUREK in October 1957. Courtesy GettyImages / Time & Life Pictures.

SEMENOV [Russ. *СЕМЕНОВ*], Nikolai Nikolaevich (1896–1986)

▪ Soviet physical chemist; discoverer of branched chain reactions in chemistry



Nikolai N. SEMENOV was born in Saratov, a town in south-central Russia. His father was Nikolai Aleksandrovich SEMENOV, a professional infantry soldier. Educated at the University of Petrograd (now St. Petersburg), he graduated with high honors in physics in 1917, the year of the Bolshevik Revolution. Invited by the University of Tomsk (western Siberia), he accepted an assistant professorship and in addition to lecturing worked at the Institute of Technology (1918–1920). Recalled to Petrograd by his former tutor Abram F. IOFFE, he worked mainly on electrical discharges in gases and electron impact phenomena at the Laboratory of Electronic Chemistry of the Leningrad Physico-Technical Institute (1927–1931), which was incorporated into the newly founded Institute of Chemical Physics of the Russian Academy of Sciences (1931) and later moved to Moscow (1943).

The Institute of Chemical Physics was created with the aim of "introducing physical theories and methods into chemistry, chemical industry, and other branches of economics." SEMENOV defined chemical physics as a "science describing the fundamentals of chemical transformations and the associated problems of substance structure." He was appointed professor and head of the Department of Combustion and Explosion Research, where he worked out his theory of chain reactions in combustion processes, self-ignition phenomena, and kinetics of chemical reactions (1931–1939). At the Institute of Chemical Physics other renowned Soviet researchers also worked temporarily on chemical kinetics such as A.F. BELAJEV (1938–1940), D.A. FRANK-KAMENETSKY (1938), Y.B. KHARITON (1926–1936), O.M. TODES (1936), and Y.B. ZEL'DOVICH (1938–1946), who developed their famous theories of combustion and detonations as well as the fundamentals of the thermal decomposition of explosives.

Prior to or simultaneously with SEMENOV's investigations, the conception of chain reactions to thermochemical reaction was advanced also independently by various other eminent researchers, such as in Germany by M. BODENSTEIN (1913), E. CREMER (1927), F. HABER (1931), and W. NERNST (1916), in the United States by H.L.J. BÄCKSTRÖM (1927), in Denmark by J.A. CHRISTIANSEN and H.A. KRAMERS (1923), and in England by C.N. HINSHELWOOD, C.H. GIBSON, and H.W. THOMPSON (1928–1929).

SEMENOV investigated the question why chemical chain reactions occur and revealed their importance in connection with the phenomenon of explosion. In his monograph *Chain Reactions* (1934) he developed the theory of nonbranching reactions and showed the wide distribution of chain reactions in chemistry. He and his associates investigated experimentally the breaking of reaction chains on walls and in the volume of a container, the degeneration of chain branching, positive and negative interaction of chains, and the mechanism and role of free atoms and radicals in series chain processes. SEMENOV and the British chemist Sir Cyril HINSHELWOOD received together the 1956 Nobel Prize for Chemistry "for their researches into the mechanism of chemical reactions." HINSHELWOOD had worked on reaction rates and reaction mechanisms, particularly that of the combination of hydrogen and oxygen to form water.

SEMENOV was Secretary of the Department of Chemical Sciences of the U.S.S.R. Academy of Sciences (1961) and honorary doctor of the Universities of Oxford (1960), Brussels (1962), Milan (1964), Budapest, Prague, and Berlin (1965). He also obtained many national awards for his numerous contributions to chemical physics. Since 1990 the Institute of Chemical Physics at Moscow has carried his name, the *N.N. Semenov Institute of Chemical Physics* of the Russian Academy of Sciences. On his initiative, a number of scientific institutes, dedicated to research on combustion and chemical kinetics, were established in the former Soviet Union such as at Novosibirsk, Tomsk, and Yerevan. SEMENOV was also cofounder of the Moscow Institute of Physics and Technology (MIPT), which was established in 1946. The *N.N. Semenov Gold Medal* is awarded by the Russian Academy of Sciences to Russian and foreign scientists for outstanding contributions in Chemical Sciences.

Astronomers named a minor planet (asteroid 2475 SEMENOV) after him.

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NOTE. His name has also been transliterated as SEMENOFF, SEMYENOV, and SEMYONOV.

SHOEMAKER, Eugene Merle (1928–1997)

▪ U.S. geologist and planetary scientist; founder of the scientific study of impact cratering and father of astrogeology

Eugene M. SHOEMAKER was born in Los Angeles, CA. His father was George Estel SHOEMAKER, a teacher, farmer, trucker, and studio grip. After schooling in New York and graduation from high school in Los Angeles he entered CalTech in Pasadena at the age of 16 (1944). There he graduated and got a master's degree (1948). SHOEMAKER, who was interested in rocks and minerals in his childhood, followed this inclination all his life. His first work was for the USGS in the uranium exploration program in Grand Junction, CO. Assigned to map craters formed by nuclear explosions at the Nevada test site, he discovered that both nuclear craters and the Meteor Crater in Arizona had a very similar crater ejecta stratigraphy. Continuing his education at Princeton University and becoming interested in terrestrial and lunar craters and the possible role of asteroids, he received his Ph.D. with a thesis entitled *Penetration Mechanics of High Velocity Meteorites, Illustrated by Meteor Crater, Arizona* (1960). Together with the U.S. astronomer Edward C.T. CHAO he discovered in 1960 the natural occurrence of coesite – a shock-induced high-pressure polymorph of silica – at Meteor Crater and shortly after also in the Ries Basin, Bavaria, thus not only solving an old geologic puzzle that these crater structures were indeed formed by meteorite impact but also introducing coesite as a diagnostic tool in distinguishing impact in other geologic structures. Several months later, he discovered at Meteor Crater another, even higher-temperature, higher-pressure polymorph of quartz, which had been produced shortly before by the Soviet mineralogist Sergei M. STISHOV using static high pressures and which SHOEMAKER called "stishovite."

SHOEMAKER is credited with creating the Astrogeology branch of the USGS: the *Astrogeology Research Program,* dedicated to the study of the geology of extraterrestrial solid objects, was founded in 1961 as a subgroup of the USGS, with SHOEMAKER serving as its first director. In addition, he established the Flagstaff Field Center in 1963. By mapping and analyzing craters on the Moon, both from telescopes and from a series of lunar spacecraft, such as Ranger, Surveyor, Lunar Orbiter, and Apollo, and with Voyager the cratered moons of some outer planets, he was among the first to recognize that by measuring the relationship between crater density and diameter the age of a planetary surface could be inferred. To confirm the impact of craters, he also demonstrated that the size distribution and flux of existing objects that could hit the Earth is closely correlated with the number, size, and age distribution of the relatively recent craters found on the Earth and Moon. Together with Robert J. HACKMAN, a USGS geologist, he suggested in 1962 that radial streaks extending from some lunar impact craters for several multiples of the crater's diameter – so-called "lunar rays" – were the result of fragmented ejecta material superposed on all other surrounding terrains, which places rayed craters in the youngest (Copernican) system of their defined time-stratigraphic classification.

Together with his wife Carolyn and with David H. LEVY, both astronomers, he made the famous discovery of the comet SHOEMAKER-LEVY 9 (or SL9), a fragmented comet that looked like "a string of pearls" whose spectacular impact on Jupiter could be observed from telescopes of the Earth (1994). Ironically, he died "on impact" in a car accident in Central Australia on his way to doing fieldwork on some impact craters.

His scientific output includes 195 publications and more than 200 abstracts. He received many honors and awards, such as the Wetherill Medal (1965) of the Franklin Institute, the NASA Medal (1967), the Day Medal (1982) and the Gilbert Award (1983) of the Geological Society of America, the first Barringer Award (1984) and the Leonard Medal (1985) of the American Meteoritical Society, the Kuiper Prize (1984) of the American Astronomical Society, the National Medal of Science (1992), and the Bowie Medal (1996) of the American Geological Union. From 1980 he was also a member of the National Academy of Sciences. The formerly Teague ring structure in western Australia has been named *Shoemaker Impact Structure* (1998). A minor planet (asteroid 2074 SHOEMAKER) is also named for him.

His greatest honors came posthumously: a small portion of his ashes was sent by NASA to the Moon aboard Lunar Prospector (1999), and in March 2000 NASA's NEAR (Near-Earth Asteroid Rendezvous) spacecraft was renamed *NEAR Shoemaker*. In 2001, the *Shoemaker Center for Astrogeology Building* on the USGS Flagstaff Science Center campus was named in memory of him.

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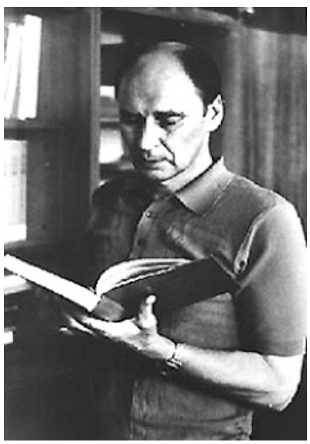
PICTURE. From the USGS Photographic Library, Portraits Collection; http://libraryphoto.cr.usgs.gov/ports.htm.

NOTE. SHOEMAKER was author or coauthor of 202 publications, *see* list http://astrogeology.usgs.gov/About/People/GeneShoemaker/00gene_bib.txt.

SOLOUKHIN [Russ. *Солоухин*], Rem Ivanovich (1930–1988)

▪ Soviet combustion physicist and gas dynamicist



Rem I. SOLOUKHIN was born in Gus-Khrustalny, a village near Vladimir in Central Russia. After graduating from Lomonosov University in Moscow, he received a diploma from the Faculty of Thermal and Molecular Physics (1953), which involved first pioneering shock-tube experiments in the U.S.S.R. and the development of gauges for recording detonation pres-

sure. After working at the Power Engineering Institute of the U.S.S.R. Academy of Sciences (1953–1958) and the Moscow Physico-Technical Institute (1958–1959), he became head of the laboratory of the AN SSSR Siberian Division's Institute of Hydrodynamics (1959–1967). SOLOUKHIN received the first Ph.D. in physics and mathematics of the newly founded Novosibirsk State University (1962) to which he later served as the first Dean of Physics and Pro-Rector for Education and Research. He was appointed professor at the University of Novosibirsk (1965), became deputy director of the AN SSSR Siberian Division's Institute of Nuclear Physics (1967–1971), director of the AN SSSR Siberian Division's Institute of Pure and Applied Mechanics at Academgorod, and eventually director of the Heat and Mass Transfer Institute of the Belarus Academy at Minsk (1976–1988).

His research was mainly devoted to the combustion of gases and the kinetics of high-temperature chemical reactions in shock waves, in particular to the structure of detonation waves in gases and the processes by which combustion is transformed into detonation. He also studied the propagation of shock waves in inhomogeneous media and the problem of shielding shock waves, developing new techniques for the diagnosis of the main shock wave parameters, such as pressure, density, and temperature. In cooperation with Nikita A. FOMIN, N.N. KUDRIAVTSEV, and S.S. NOVIKOV he conducted research on the diagnostics of molecular levels in nonequilibrium flows of gasdynamic lasers.

The results of his investigations were published in several books and over 300 research articles. Together with Bogdan V. VOITSEKHOVSKY and Yakov K. TROSHIN he won the reputed Lenin Prize (1965) for fundamental investigation of detonation. He also obtained a number of other medals. SOLOUKHIN was a member of the Belarus Academy of Sciences and a corresponding member of the U.S.S.R. Academy of Sciences. He also served as a member of the editorial board of the international journal *Experiments in Fluids*.

The *Soloukhin Medal*, instituted by the 12th International Colloquium on Gas Dynamics of Explosions and Reactive Systems (1989), is awarded to scientists for outstanding experimental studies in the field of gas dynamics.

Astronomers have named a minor planet (asteroid 9741 SOLOUKHIN) after him.

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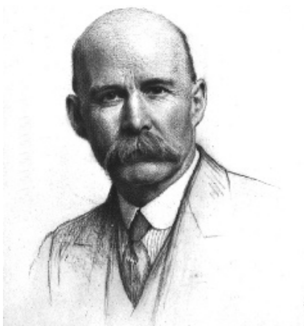
PICTURE. Courtesy Prof. Nikita A. FOMIN, Heat & Mass Transfer Institute, Minsk, Russia.

NOTE. His name has also been transliterated as SOLOUCHIN.

STANTON, Sir Thomas Edward (1865–1931)

▪ British engineer and physicist; pioneer of supersonic wind tunnel testing



Sir Thomas E. STANTON was born in Atherstone in Warwickshire (central England), the son of the landowner Thomas STANTON. After attending the Atherstone Grammar School, he became an apprentice at a company in Leicester, being trained there in general engineering and millwrights (1884–1887). In 1888, he entered Owens College at Manchester and followed the engineering course given at the Whitworth Laboratory under the engineer and physicist Osborne REYNOLDS. He took his B.Sc. at Victoria University, Manchester, and continued working in REYNOLDS' laboratory as a Junior and later as Senior demonstrator (1891–1896), and later as resident tutor in mathematics and engineering at the Hulme Hall of Residence, Manchester (1892–1896). After working as a senior assistant lecturer in engineering at the University College, Liverpool (1896–1900), and shortly serving as professor of engineering at Bristol University College (1899–1900), he was appointed Superintendent of the Engineering Department of the National Physical Laboratory (NPL) in Bristol, a position he held from 1901 until his retirement in 1930.

STANTON's main field of interest was fluid flow and friction and the related problem of heat transmission. At NPL he began to tackle various problems of public interest, such as the study of wind forces on bridges, roofs, and other structures. He performed model experiments at reduced scale and, using a small vertical wind tunnel of circular section 2 ft in diameter, exposed his model structures to an artificial current of air (1902–1907). After verifying his model analysis by full-scale experiments and realizing that invaluable information could be obtained by applying this concept, he extended this method to various problems of airplane and airship design. After 1908 he devoted himself to problems of airplane and aircraft design and the dissipation of heat from air-cooled engines.

In the early 1920s STANTON conducted research into the subject of aerodynamic drag to motion at very high speeds, which became important for the motion of fast projectiles and propeller blades with high tip speeds. For this purpose he designed at NPL the first British supersonic wind tunnel which he called "wind channel." It had a diameter of 0.8 in. (20.3 mm), which only allowed the testing of tiny-scale model projectiles 0.09 in. (2.3 mm) in diameter up to approx. $M = 2$. However, he was able to correlate his results obtained from testing tiny model projectiles with those from firing tests on artillery ranges. Early tests were also made on airscrew blade sections and bullet shapes. After provision of a more powerful air-compression capability, a larger and continuously operated wind tunnel, 3.07 in. (78 mm) in diameter, $M = 3.25$, was put into operation (1922). He tested airfoils in this tunnel, even to the extent of determining the pressure distribution over model airfoils of only half-an-inch (12.7-mm) chord.

STANTON also contributed to other fields of aircraft engineering, such as film and boundary lubrication in engines, and the understanding and testing of metal fatigue.

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STANYUKOVICH [Russ. *СТАНЮКОВИЧ*], Kirill Petrovich (1916 –1989)

▪ Soviet theoretical physicist and eminent gas dynamicist

Kirill P. STANYUKOVICH studied at the Mechanical-Technical Faculty of Moscow State University and graduated with a

specialization in astronomy (1939). While still a student he already showed a keen interest in meteorite impact and published a theory on the nature of craters on the Moon, expounding the idea that the craters are the result of bombardment of the Moon over millions of years (1937). In 1942, he entered the fields of shock wave and detonation physics and worked at the Soviet Artillery Academy under the supervision of Prof. Lew D. LANDAU, then director of the section of theoretical physics at the Institute of Physical Problems of the U.S.S.R. Academy of Sciences. Together with LANDAU he developed a concept of a barotropic equation of state for detonation products that formed the basis of modern explosion physics, and he analytically treated convergent spherical shock waves (1944, published in 1955). In 1947, he received his Ph.D. in technical sciences. As a result of his courses on gas dynamics he published his first monograph on the theory of unsteady flows (1948), which, later translated into English under the title *Unsteady Motion of Continuous Media* (1960), quickly became a classic textbook on the field of shock waves and detonation also in the Western World. In 1954, he first showed that a power law entropy profile (with index $b = 3\gamma - 1$) is mathematically equivalent to the case of an isentropic gas ($b = 0$); *i.e.*, presenting Riemann invariants and thus resulting in an essential simplification of the system of Euler equations which become linear.

From 1950 he worked at the N.E. Baumann Institute of Moscow State Technical University (BMSTU) and became professor in 1952. Together with various other Soviet professors he laid the scientific foundations of the M4 Department Gas-Dynamic Impulse Devices at BMSTU. In an article entitled *Problems of Interplanetary Flights* (1954), he treated the subject of nuclear-powered rockets. Prior to Sputnik's flight (1957), he wrote a paper on the problems associated with artificial Earth satellites (1955). As a coauthor he contributed to Filipp A. BAUM's monograph *Physics of Explosions* (1959, 1975). He also wrote two popular-science books on cosmology that were translated into English: *Matter and Man* (1962) and *There Are Seven Elements in the World* (1963).

STANYUKOVICH was a member of the Interdepartmental Commission on Interplanetary Communications (ICIC), an organization established by the Soviet Presidium (1957), and from 1954 a charter member of the V.P. Chkalov Central Aero Club of the Soviet Union.

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PICTURE. Courtesy Prof. Gennadij I. KANEL', Institute for High Energy Densities of the Russian Academy of Sciences, Moscow, Russia.

NOTE. His name has also been transliterated as STANJUKOVIČ.

STODOLA, Aurel Boleslav (1859–1942)

▪ Hungarian-born Swiss mechanical engineer and fluid dynamicist

Aurel B. STODOLA was born in the Hungarian town Liptovs-ký Mikuláš (now Liptószentmiklós, eastern Czechia). He was the second son of Andreas STODOLA, a leather-belt manufacturer. He studied at the Polytechnic School of Budapest (1876–1877), the University of Zurich (1877–1878), and finally at the Eidgenössische Technische Hochschule Zürich (ETHZ, 1878–1880), from which he graduated as a mechanical engineer with the highest distinction (1881). He worked briefly in the workshops of the Hungarian State Railways in Budapest and continued his studies in Berlin, where he attended lectures of the German physicist Hermann VON HELMHOLTZ and the German mathematician Paul DU BOIS-REYMOND. After gaining further practical experiences in Paris, he worked as a designer in the Prague steam engine factory Ruston & Co. In 1892, he was offered the chair of thermal machinery at ETHZ, where he remained until his retirement (1892–1929).

His main subject of research was the theoretical treatment of steam and gas turbines and centrifugal compressors. Most of his results were published in his internationally widely acknowledged book *Die Dampfturbinen und die Aussichten der Wärmekraftmaschinen* (1903), which, translated into English and French, saw six editions and substantive revisions. STODOLA investigated in great detail the principal parts of the steam turbine, namely, the nozzles and blades. When STODOLA began his studies, only a rudimentary theory of supersonic flow in Laval nozzles was available. He was the first to perform systematic measurements of the axial pressure distribution at different back pressures and graphically demonstrated the conditions under which a supersonic flow in Laval nozzles occurs. When driving Laval nozzles at high back pressures he noticed a dramatic increase in pressure and correctly related his observation to a *Verdichtungsstoß* (condensation shock); *i.e.*, a shock wave, as was previously derived mathematically by Bernhard RIEMANN (1859). Since a profound knowledge of the proper operation characteristics of a Laval nozzle is of greatest practical importance for the efficiency of steam turbines, STODOLA verified his theoretical results by carrying out many experiments and also established the various sources of losses and their magnitude. Typically for him, he managed to express complicated fluid dynamic conditions in simple formulae ready for practical use in engineering, for example steam flow through clearances and labyrinths, and friction effects of disks. He eventually became the leading expert in Europe on steam turbines.

Besides the thermodynamic and fluid dynamic treatment of steam, STODOLA investigated mechanical and thermal stresses in bodies of basic geometry, such as plate shells and rotating disks as well as of real turbine parts in order to estimate the forces due to the steam pressure, steam temperature, and the motion itself. He also had a strong sense of social responsibility, as evidenced in his later work *Gedanken zu einer Weltanschauung vom Standpunkt des Ingenieurs* ("Thoughts on a Worldview from the Standpoint of an Engineer," 1931). STODOLA's assistants Jakob ACKERET and Gino FANNO became famous gas dynamicists.

The *Stodola Lecture*, established by ETHZ in 2004, is given by an internationally recognized expert in the field of mechanical and process engineering, which is selected by the department faculty and is awarded the *Stodola Medal*.

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PICTURE. Courtesy Bildarchiv ETH-Bibliothek, Zurich, Switzerland.

NOTE. *See also* 23 pictures of Aurel STODOLA, "bildarchivonline" der ETH Bibliothek, Zürich; http:/\ba.e-pics.ethz.ch/ETH_Bibliothek/Standard/.

STOKES, Sir George Gabriel (1819–1903); from 1889 first Baronet

▪ Irish mathematical physicist; founder of geodesy

Sir George G. STOKES was born in Skreen (County Sligo, Ireland) into an Anglo-Irish family of clerical tradition. His

father Gabriel STOKES was rector of Skreen and vicar-general of Killala (County Mayo). After receiving an early education in mathematics and geometry in Skreen, Sligo and Dublin (1832–1835), he went to Bristol College to study the traditional curriculum, but with an emphasis on mathematics, under Francis NEWMAN (1835–1837). At his final examination (1837) he won a prize "for eminent proficiency in mathematics" and continued his study of mathematics at Pembroke College, Cambridge (1837–1841). After graduation he was immediately elected a Fellow of the college. Following the suggestion of William HOPKINS, one of his teachers, he took up the subjects of hydrodynamics and optics in addition to mathematics.

STOKES' earliest papers were on fluid motion (1842–1846): he worked out (1) a mathematical solution to the problem of finding the steady motion of an incompressible fluid in the interior of a rectangular box that is given any motion whatever, starting from rest with the contained liquid at rest (1843, 1846); (2) a theory of the viscosity of fluids and its influence in fluid motion, which constitute the complete foundation of hydrokinetics and of the equilibrium and motion of elastic solids (1845); (3) a classical theory on a discrepancy concerning some solutions of equations of compressible gas dynamics, thereby correctly deriving the jump conditions that discontinuous solutions must satisfy (1848); (4) a theory of oscillatory waves (1849), thereby also addressing the determination of the motion of steep deep-sea waves and showing that the difference in level between crest and hollow is $^{7}/_{40}$ of the wavelength; and (5) a solution to the difficult problem of internal friction effects of fluids on the motion of pendulums (1850).

Already in 1846 regarded as an authority on hydrodynamics, STOKES was asked by the British Association for the Advancement of Science (BAAS) to give a report on its current state, which he did in a concise, masterly manner. With this profound knowledge of fluid dynamics he began 2 years later to tackle the difficult problem of waves of finite amplitude, which he solved by introducing surfaces of discontinuity in the velocity and density of the medium, thus pioneering the modern concept of a shock wave profile. In the period 1847–1849, he collaborated with the British engi-

neer William THOMSON (the later Lord KELVIN), his close friend, in a series of articles on hydrodynamic principles, which THOMSON applied to electrical and atomic theory.

In 1849, STOKES was elected to the Lucasian professorship of mathematics at Cambridge, which came with the direction of the observatory. Since the previous holders of that office, James CHALLIS and George B. AIRY, used to give lectures not only on hydrodynamics but also on acoustics, he continued this tradition and entered a branch of physics to which he made many outstanding contributions. STOKES' proposed theory of the propagation of a wave of finite amplitude (1848) was in contradiction to CHALLIS' proposed theory. But later on, due to arguments of Lord KELVIN and Lord RAYLEIGH, his former student, that his proposed motion would violate the conservation of energy, he retracted the idea of such motion, and when he edited his complete works in 1880, he did not reproduce his (correct) 1848 proof of the jump conditions. His treatise on the shock wave problem only covered a very small part of his activities; his main research topics were investigations of the internal friction (or viscosity) in fluids, *fluorescence* (a term he invented in 1852), geodesy, optical spectroscopy, the wave theory of light, and pure mathematics.

STOKES became a Fellow (1851) of the Royal Society and was the first man since Sir Isaac NEWTON to hold the three positions of Lucasian professor of mathematics (1849–1903), secretary (1854–1885), and president (1885–1890) of the Society. He was also president of the Cambridge Philosophical Society (1859–1861) and the BAAS (1869). He received honorary degrees from several universities and awards from numerous scientific societies, such as the Rumford Medal (1852) and the Copley Medal (1893) of the Royal Society of London, and was made a baronet (1889). When he died at the age of 84, the world lost not only one of its greatest promoters of general fluid dynamics, but also a pioneer of shock wave physics. Like Lord KELVIN and James C. MAXWELL he was a member of the "Cambridge School of Natural Philosophers," which helped to revolutionize science in Victorian Britain.

In radiation physics the *Stokes parameters* are a set of four values that describe completely the state of polarization of a beam of electromagnetic radiation. In fluid dynamics his name is connected with the terms *Navier-Stokes equations* and *Stokes law*, and in optics with *Stokes shift* and *Stokes lines*. The *Stokes Medal*, established in 1999 by the Royal Society of Chemistry (RSC), London is awarded biennially for outstanding and sustained contributions to analytical science by someone working in a complementary field, which has led to developments of seminal importance to chemical analysis.

Astronomers named a crater on the near side of the Moon, a crater on Mars, and a minor planet (asteroid 30566 STOKES) after him.

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STRUTT, John William (1842–1919); from 1873 third Baron RAYLEIGH

▪ British experimental and mathematical physicist

John W. STRUTT was born at Langford Grove, Maldon, in the County of Essex. He was the eldest son of John James STRUTT, second Baron RAYLEIGH. After schooling at Eton and Harrow and private tutoring, he entered Trinity College, Cambridge (1861), graduated from there with a B.A. in mathematics (1865), and became a Fellow of Trinity College (1866). This was followed by a period of touring the Continent and visiting the United States. Upon returning to England (1868) he decided to fully dedicate himself to science and began to install his private laboratory at the family seat in Terling Place at Witham, Essex. After the death of his father (1873), he succeeded to the title of third Baron RAYLEIGH. After the death of James C. MAXWELL he took over as chair at Cambridge University and became second Cavendish professor of experimental physics (1879–1884). After his retirement (1885) he continued his research in his private laboratory at Terling Place. At the Royal Institution of Great Britain he served as professor of natural philosophy (1887–1896).

He also gave freely of his time and energy to matters of public interest and scientific committees of government and professional organizations. RAYLEIGH served as secretary (1884–1895) and president (1905–1908) of the Royal Society, chancellor of Cambridge University (1908–1919), president of the special government advisory committee on aeronautics (established in 1909), chairman of the Explosives Committee of the War Office, president of the British Association for the Advancement of Science (BAAS), and president of the first executive committee of the National Physical Laboratory (NPL) at Teddington.

RAYLEIGH's research covered almost the entire field of physics, but nearly three quarters of his papers deal with problems in acoustics and optics. In acoustics, starting from physiological research, he worked out a theory of resonance that established his reputation as a leading authority on sound. On a trip to Egypt (1871), which he made for health reasons, he started working on his two-volume book *The Theory of Sound* (1877–1878). Addressing questions of vibrations and the resonance of elastic solids and gases, it has remained a standard work to this day and has undergone several reprintings. In 1877, he had a dispute with George G. STOKES on his early papers (1848–1849) in which STOKES had derived a theory of sounds of finite amplitude; *i.e.*, of shock waves. He refuted STOKES' and RIEMANN's hypothesis of a discontinuous change in the thermodynamic quantities and maintained this view also in the second edition of his *Theory of Sound*, although August TOEPLER (1864) and Ernst MACH (1885, 1887, 1889) had already visualized the discontinuous nature of a shock front. Ten years before his death, however, RAYLEIGH took up this problem again and extended earlier investigations of RANKINE and HUGONIOT in his famous paper on *Aerial Waves of Finite Amplitude* (1910), a masterpiece on early shock wave research. In his later years, he also returned to his early physiological research and studied the binaural effect of hearing (1905). Today RAYLEIGH is considered one of the leading pioneers in fluid dynamics and acoustics, his studies ranging from the measurement of the minimum audible intensity of sound to the analytical treatment of shock waves, including also the first molecular-acoustic studies.

RAYLEIGH contributed much to fluid dynamics. Related to problems in acoustics, RAYLEIGH (in order to model the oscillations of a clarinet reed) described a typical nonlinear system with one degree of freedom which admits auto-oscillations, so-called "Rayleigh equation" (1877/1878). RAYLEIGH also modeled the instability of a column of liquid and predicted its decay into a chain of droplets, so-called "Rayleigh instability" (1879). He derived the growth equation for an immobile spherical gas bubble in a finite spherical volume of liquid, so-called "Rayleigh vapor bubble model" (1917). Apparently, he never studied shock waves experimentally. However, during his period as chief scientific advisor (1896–1911) to Trinity House, which maintained the fog warnings and lighthouses around the English coast, he thought about how to spread the range of fog horns within which their sound is heard as widely as possible. This requires not only sound generators of very high intensity, for example the use of trumpets and an improvement in their beam characteristic by choosing the opening of the trumpet to be small in the horizontal and large in the vertical direction. However, he estimated that even by choosing trumpets emitting a high tone (*i.e.*, a short wavelength) this would result in a very large structure, the vertical dimension required for waves about 1.2 m long being of the order of 6 m (Scient. Papers, vol. 5, p. 133). In shock wave and detonation physics a straight line on a Hugoniot plot connecting the initial and final states is called a "Rayleigh line" (1910).

RAYLEIGH also contributed to wave theory, optics, radiation, electromagnetism, spectroscopy, and to the redetermination of electrical units in absolute measure. His theory of the scattering of sunlight by small particles in the atmosphere, evolved in the so-called "Rayleigh scattering law" (1871), provided the first explanation of why the sky is blue. He investigated elastic surface waves that are generated at a boundary surface and showed that their effect decreases rapidly with depth and that their velocity of propagation is smaller than that of body waves. These so-called "Rayleigh waves" (1887) are of greatest importance for the interpretation of seismograms. In probability theory and statistics, the "Rayleigh distribution" is a continuous probability distribution. Together with the British chemist Sir William RAMSAY he discovered the inert gas argon (1895).

RAYLEIGH wrote one book and about 450 scientific articles. He was awarded the Royal Medal (1882), the Copley Medal (1899) and the Rumford Medal (1914) of the Royal Society of London, and the De Morgan Medal (1890), the London Mathematical Society's premier award. He also received special awards from over 50 learned societies and was the recipient of 13 honorary degrees. In 1904, RAYLEIGH earned the Nobel Prize for Physics and RAMSAY the Nobel Prize for Chemistry "for their investigation of the densities of the most important gases, and for their discovery of argon in connection with these studies." He died on June 30, 1919 at Terling Place, where he carried out practically all of his scientific investigations.

The *Rayleigh Medal* is the premier award of the British Institute of Acoustics (IOA) and awarded to persons renowned for outstanding contributions to acoustics. The *Rayleigh Lectures Series* is given at the International Mechanical Engineering Congress & Exhibition (IMECE) by researchers who have made pioneering contributions to the sciences and applications of noise control and acoustics.

Astronomers named a crater on the near side of the Moon and a crater on Mars after him.

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STURTEVANT, Bradford ("Brad") (1933–2000)

▪ U.S. aeronautical engineer and fluid dynamicist

After receiving his B.S. (1955) in mechanical engineering from Yale University, Bradford STURTEVANT joined Cal-

Tech's Graduate Aeronautical Laboratory (GALCIT), where he stayed for the rest of his professional career, receiving an M.S. (1956) in aeronautics and a Ph.D. (1960) in fluid mechanics. He joined the faculty in 1960 and became associate professor (1966–1971) and professor of aeronautics (1971–1995). In 1995, he was appointed Hans W. Liepmann Professor of Aeronautics.

STURTEVANT was best known in the fluid dynamics community for his research on shock waves and nonsteady gas dynamics. He interpreted nonsteady gas dynamics in the most imaginative way possible with applications ranging from noise control in motorcycle exhausts to volcanic eruptions and treatment of kidney stones with shock waves. His projects included (1) experimental and theoretical investigations of the propagation of shock waves through inhomogeneous media, including shock-excited Rayleigh-Taylor instability; (2) hydrodynamic sources of earthquakes and harmonic tremor; (3) sonic boom; (4) the effects of dissociation relaxation in hypervelocity flow; (5) shock wave physics of extracorporeal shock wave lithotripsy, including the focusing of weak shock waves; and (6) the fluid mechanics of explosive volcanic eruptions, including the explosive evolution of dissolved gas from rapidly depressurized liquids.

STURTEVANT was a dedicated member of the CalTech community, a vigorous athlete, and a proponent of fluid mechanics as a rigorous intellectual activity that spanned across scientific disciplines from medicine to geology. He held a number of administrative positions such as Executive Officer for Aeronautics and Secretary-Treasurer for Aeronautics of CalTech (1971–1976), and as an active sportsman he served terms as chairman and secretary-treasurer of the Southern California Intercollegiate Athletic Conference (1980–1986). He was a co-organizer of the 20th International Symposium on Shock Waves, held at CalTech in Pasadena (1995), and editor of the proceedings.

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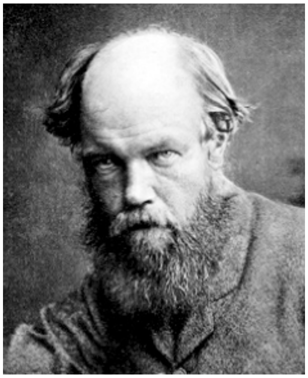
PICTURE. Courtesy Prof. Joseph E. SHEPHERD, Graduate Aeronautical Laboratories at CalTech, Pasadena, CA.

TAIT, Peter Guthrie (1831–1901)

▪ Scottish physicist and mathematician; father of science and golf



Peter G. TAIT was born in Dalkeith (a town 10 km south of Edinburgh), the son of John TAIT, a secretary to the Duke of Buccleuch. After schooling, partly together with James C. MAXWELL, he entered the University of Edinburgh to study mathematics (1847) and continued at Peterhouse College in Cambridge (1848–1852), where the mathematician and geologist William HOPKINS was his tutor. After graduating from Cambridge, TAIT became professor of mathematics at Queen's College in Belfast (1854–1860) and thereafter took the chair of natural philosophy at the University of Edinburgh (1860–1901), which he held until shortly before his death.

In the 1860s, he became interested in thermodynamics, working particularly on thermoelectricity and thermal conductivity. He collected deep-sea temperatures during the HMS *Challenger* Expedition, a prolonged oceanographic exploration cruise (1872–1876) carried out through cooperation of the British Admiralty and the Royal Society. Returning to England, TAIT began to work out corrections of his measured temperature data, which were required because of the great pressures to which his thermometers had been subjected. He investigated the compressibility of water, sea water, glass, and mercury. His isothermal equation of state (1888), the so-called "Tait equation," was later modified by others to also match compressibility data of statically compressed organic liquids (HIRSCHFELDER ET AL. 1964; ATANOV 1966) as well as for use in underwater explosions to shock pressures up to 90 kbar (KIRKWOOD 1942; COLE 1948).

TAIT also studied percussion phenomena both theoretically and experimentally by a special guillotine-like percussion machine that was capable of recording contact times. He collaborated with William THOMSON, (from 1892 Lord KELVIN), on the book *Treatise on Natural Philosophy* (1888). Here they treated the collision of spherical bodies and introduced a "restitution coefficient," which they defined as the quotient of velocities after and before impact. To study the impact of a golf ball, TAIT used a ballistic pendulum faced with clay into which the ball was driven. For the contact phase between club and ball he obtained a time duration as short as about 5 ms and estimated the impact force on the order of tons. TAIT was apparently the first to study the lift on a spinning ball in the game of golf. His golf-ball studies, published in the British journal *Nature* in a series of articles, revealed that underspin provided the great secret of long driving (1890–1891). However, the markings on balls went through extensive development before the present dimpled surface was considered to be near the optimum design. TAIT's third son was Frederick Guthrie TAIT, who became the leading amateur golfer (1893) and won two Open golf championships (1896, 1898).

In 1853, he became interested in quaternions, a new advanced algebra of complex numbers in more than two dimensions invented in 1843 by the Irish mathematician William Rowan HAMILTON that gave rise to vector analysis and was instrumental in the development of modern mathematical physics. He also carried out pioneering studies on the topology of knots, which he published in his book *An Elementary Treatise on Quaternions* (1873; 3rd edn. 1890). In mathematics knots are defined as closed, non-self-intersecting curves that are embedded in three dimensions and cannot be untangled to produce simple loops. In collaboration with William John STEELE, he published *A Treatise on Dynamics of a Particle* (1882) and contributed to the kinetic theory of gases (1886–1892). He published about 360 articles and reviews.

TAIT was a Fellow of the Royal Society of Edinburgh (from 1860) and acted as its general secretary (1879–1901). For his various mathematical and physical researches TAIT was awarded the Royal Medal (1886) of the Royal Society of London. He was also awarded other prizes in England and Scotland. He was a fellow or member of the Danish, Dutch, Swedish, and Irish scientific academies.

The *Tait Professorship of Mathematical Physics* is an established chair within the University of Edinburgh.

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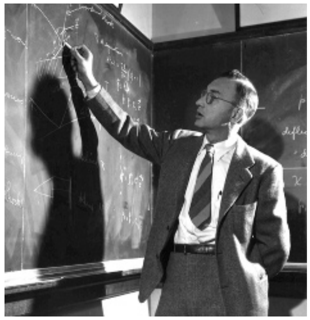
NOTE. A comprehensive *Provisional bibliography of Peter Guthrie TAIT* was compiled by Chris PRITCHARD (British Society for the History of Mathematics) for the *Peter Guthrie TAIT (1831–1901): Centenary Meeting*. Roy. Soc. Edinburgh (July 2001); *see*
http://www.maths.ed.ac.uk/~aar/knots/taitbib.htm.

TAUB, Abraham Haskel (1911–1999)

▪ U.S. mathematician and theoretical fluid dynamicist; founder of the theory of relativistic simple waves and shocks



Abraham H. TAUB was born in Chicago, where he studied mathematics at the University of Chicago and earned his B.S. (1931). After working as an instructor in mathematics and earning a Ph.D. (1935) in mathematical physics at Princeton University, he became at Princeton's Institute for Advanced Study (IAS) assistant (1935–1936), member (1940–1941), theoretical physicist (1942–1946), and Guggenheim Fellow (1947–1948).

Closely working there together with John VON NEUMANN, he got involved in digital computers, numerical analysis, and problems in shock physics theory, particularly in shock interactions. In 1942, he collaborated with Prof. Walker BLEAKNEY, then head of the Palmer Physical Laboratory at Princeton University, and developed a theory of the shock tube, independently of previous existing theories in Germany (KOBES 1910; HILDEBRAND 1927; SCHARDIN 1932). Together they investigated shock wave interactions in gases, from both the experimental and theoretical points of view. This work was for a long time the basis for many subsequent studies on this subject. During the war he also collaborated in a number of projects on dynamic effects in structures caused by blast waves and the detonation of high explosives.

After World War II, he was called by the University of Illinois in Urbana and became professor of mathematics (1948–1964) and head of the Digital Computer Laboratory (1961–1964). He built a computer that, based on John VON NEUMANN's plans and called "ORDVAC" (Ordnance Variable Automated Computer), was completed in 1952 and delivered to the Aberdeen Proving Ground. A subsequently built computer, named ILLIAC (Illinois Automated Computer), remained at Illinois and was the prototype for several other computers.

He became professor of mathematics at UC Berkeley in 1968 and remained there until his retirement (1978). In the late 1940s, TAUB began working on 1-D shock wave propagation in relativistic hydrodynamics, which is important in the numerical simulation of supernova explosions, and on impul-

sive gravitational waves. He derived the relativistic Rankine-Hugoniot equations (1948). The relativistic version of the Hugoniot adiabat is called the "Taub adiabat." The relativistic hydrodynamic equations introduced by TAUB are called the "Taub equations." A peculiar unstable solution of EINSTEIN's equations of general relativity is called the "Taub Universe."

TAUB volunteered to undertake the labor of assembling and editing the manuscripts of his friend John VON NEUMANN, which made possible the publication of his six-volume *Collected Works John von Neumann* (1963). He also edited the book *Studies in Applied Mathematics* (1971) and, with Sidney FERNBACH, coedited the book *Computers and Their Role in the Physical Sciences* (1970). Besides his numerous engagements in research and teaching, he was also interested in foreign research activities and worked as a visiting scholar at the ETH Zurich (1954) and the Universities of Cambridge (1969–1970), Chile (1972), and Oxford and Paris (1975).

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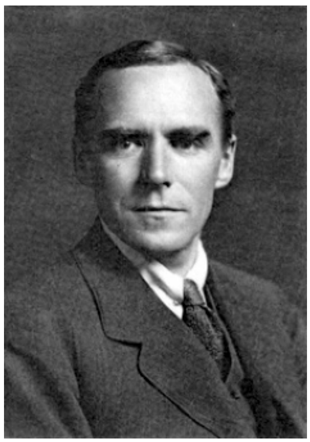
PICTURE. Courtesy Prof. Calvin C. MOORE, Dept. of Mathematics, University of Berkeley, CA. The picture shows Dr. TAUB at the blackboard treating Mach reflection.

TAYLOR, Sir Geoffrey Ingram (1886–1975)

▪ British physicist, applied mathematician, and engineer



Sir Geoffrey I. TAYLOR was born in London. He was the elder son of the artist Edward Ingram TAYLOR. He was educated in mathematics and natural sciences at University College School, London and Trinity College, Cambridge. After earning a prize fellowship (1910) he carried out research at Cavendish Laboratory in Cambridge on the mechanics of fluids and solid materials and their applications in geophysics and engineering. Already in his second paper, published in the same issue of the *Proceedings of the Royal Society* as Lord RAYLEIGH's famous paper on shock waves (1910), TAYLOR made independently a first estimate of the thickness of a shock front, which essentially supported RAYLEIGH's conclusions on the structure of shock waves. In the same year, he was elected Fellow at Trinity College, which provided support and freedom to pursue his research for up to 6 years, and became Schuster Reader at

Cambridge in dynamical meteorology (1911). Following the HMS *Titanic* disaster (April 15, 1912), he was invited as a meteorologist on an expedition to observe the paths of icebergs in the North Atlantic. During the expedition of the HMS *Scotia* to the North Atlantic (1913) he measured the vertical distributions of wind strength and direction, temperature, and humidity to a height of about 2,500 m using instrument-carrying kites. These studies of vertical transfer of heat and momentum and water vapor in the friction layer of the atmosphere stimulated other fields of his research in fluid dynamics. TAYLOR's work on turbulent motion in fluids, leading to his publication *Eddy Motion in the Atmosphere* (1915), won him the prestigious Adams Prize (1915) of the Faculty of Mathematics at the University of Cambridge. His investigations of the turbulence transfer process in the friction layer of the Earth's atmosphere led to his paper *Skin Friction of the Wind on the Earth's Surface* (1916).

During World War I, he worked at the Royal Aircraft Factory in Farnborough on the design and operation of airplanes. Stimulated by aeronautical problems, such as induced stress in propeller shafts under torsion, he got involved with studying the physical processes that limit the strength of solid materials. Together with his student Alan Arnold GRIFFITH he set up a method for detecting stress concentrations in shafts under torsion by observing the displacement of a soap film (1917). After various teaching activities at Trinity College, TAYLOR continued his research at Cavendish Laboratory as Yarrow Research Professor (1923–1952). In this period, he studied the mechanism of plastic deformation of metal crystals and published his famous "dislocation theory" (1934), which assumes that during work hardening the flow stress S is proportional to the square root of the strain s. His experimental observations on the deformation of crystals (1938) indicated that the stress-strain curve for many cubic crystals is parabolic (*i.e.*, $S \propto s^{1/2}$), the constant being temperature dependent, and that the crystals deform by the motion of dislocation on specific crystallographic planes in specific directions.

TAYLOR also contributed much to the understanding of the turbulent motion of fluids and developed a theory describing velocity fluctuations by a statistical method (1935–1939). The development of his ideas about turbulence was aided by his previous experience in meteorology and his increasing acquaintance in the 1930s with turbulent flow systems relative to aeronautics and supersonic wind tunnel measurements, which he carried out together with John W. MACCOLL.

In the period 1939–1945, he was a consultant to various civil and military authorities on high explosives. For example, he reported to the Civil Defense Research Committee (CDRC) of the Ministry of Home Security and was a member of the Physics of Explosives Committee (Physex) of the Ministry of Supply. His numerous studies cover a wide field on detonation, blast waves, underwater explosions, and associated mechanical damage effects. He participated also in the Manhattan Project (1942–1945) at Los Alamos and analytically treated blast effects of the first nuclear explosion, which earned him the U.S. Medal for Merit (1946). After World War II, he resumed his work at the Cavendish Laboratory for another 20 years. Together with A.C. WHIFFIN he worked out a test method to determine the strength of shock-loaded samples at high strain rates, the so-called "Taylor test" (1948). He theoretically demonstrated that the high-pressure wave of a planar detonation passing through a high explosive is immediately reduced, leading to a pressure-relief wave, a rarefaction, the so-called "Taylor wave" (1949). He also showed that the interface of two fluids becomes unstable when the fluid of higher density is forced into another one of lower density, the so-called "Rayleigh-Taylor instability" (1950).

TAYLOR wrote over 200 scientific papers and articles, nearly all of which were later republished by Cambridge University Press in four volumes (1958–1971). He was knighted (1944) and elected to honorary membership or fellowship by many international societies. He received many honorary degrees and awards such as the Copley Medal (1944) of the Royal Society of London, the Kelvin Medal (1959) of the Institute of Physics, the James Watt Medal (1965) of the Institution of Mechanical Engineers, and the von Kármán Medal (1969) of the American Institute of Aeronautics and Astronautics (AIAA).

Since 1976, the *G.I. Taylor Memorial Lecture* is given annually by renowned fluid dynamicists at the University of Florida. Since 2003, the *G. I. Taylor Medal* is awarded by the Society of Engineering Science, Inc. (USA) for outstanding research contributions in either theoretical or experimental fluid mechanics or both.

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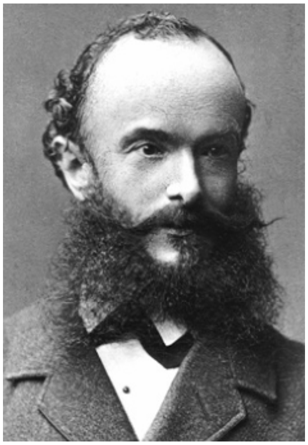
NOTE. For biographical information on G.I. TAYLOR *see also* the Navigational Aids for the History of Science, Technology & the Environment (NAHSTE) Project;
http://www.nahste.ac.uk/pers/t/GB_0237_NAHSTE_P1870/.

TOEPLER [or TÖPLER], August Joseph Ignatz (1836–1912)

▪ German experimental physicist and inventor; the first to visualize shock waves

August J.I. TOEPLER was born in Brühl (near Cologne), the son of Michael TOEPLER, an instructor of the Catholic school teacher seminar and royal music director. Although very talented in music and painting, he decided to dedicate his life to natural philosophy. He studied physics, chemistry, and mathematics at the Royal Technical Institute in Berlin (1854–1858) and graduated as a chemist. After completing his military service, he entered the Agricultural College at Poppelsdorf, a small town near Bonn. Initially working as an experimental chemist (1859–1862), he soon became a lec-



turer (1862–1864) on physics and chemistry and took his Ph.D. (1860) at the University of Jena.

TOEPLER invented various scientific instruments and contributed to the measurements of acoustic, optical, and magnetic parameters. At Poppelsdorf he also invented his famous "schlieren method" (1864). Initially he intended to apply this high-sensitivity optical method to the visualization of sound waves; however, when experiments with organ pipes failed, he turned to strong acoustic waves, which he generated by electric sparks. Since high-sensitivity films were not yet available to him, he observed the propagation and reflection wave phenomena subjectively using a stroboscopic method. He modified the Knochenhauer circuit (1858), a loose coupling of two electric discharge circuits, and applied the primary spark to generate the shock wave and the second spark, which, being fired shortly thereafter, acted as a light source. This allowed him to "freeze" the supersonic wave motion repetitively at about 20 Hz. TOEPLER made correct pen-and-ink drawings of the observed shock fronts and even from the pinched discharge channel, which looked so realistic that often modern shock physicists regarded them as photographs. He first noticed the density jump at the shock front, but he did not attempt to investigate shock waves in more detail. In order to generate stronger spark waves he improved his high-voltage discharge circuit and devised a 2-disc electrostatic influence generator. Manufactured in Berlin by the German Wilhelm HOLTZ, so-called "Toepler-Holtz machine" (1865), it was capable of quickly charging the Leiden jars to a higher voltage.

After holding the chair of chemistry and chemical technology at the Polytechnikum Riga (1864–1868), TOEPLER was appointed professor of physics at the prestigious University of Graz (1868–1876) and the Polytechnikum Dresden (1876–1900). In Graz, TOEPLER, together with his friend Ludwig BOLTZMANN, tackled again the problem of visualizing sound waves and measuring the threshold of hearing. Using a Jamin-type interferometer, they obtained for the eardrum a displacement of about 50 nm (1870). Modern measurements, however, have shown that the displacement at the threshold of hearing is even much smaller and only on the order of 0.01 nm.

TOEPLER became a corresponding member of the Academies of Vienna (1874), Berlin (1879), and Munich (1896) and a full member of the Royal Saxon Academy (1885) and the German Academy of Sciences Leopoldina Carolina (1879). He was awarded an honorary doctorate from the Universities of Heidelberg (1886), Dresden (1895), and Riga (1906). To commemorate his greatest scientific achievement, in 1912 his wife inscribed on his tombstone the epitaph *August Toepler – Er sah als Erster den Schall* ("August Toepler – The first to see sound"). Obviously, she was not aware that he visualized with his invented schlieren method spark waves (*i.e.*, weak shock waves) rather than sound waves.

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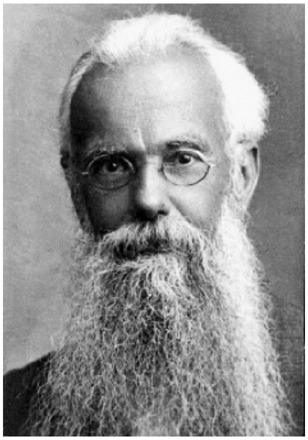
PICTURE. Courtesy Archives of TU Dresden, Photo Collection, Dresden, Gemany.

NOTE. TOEPLER spelled his name *TOEPLER*. However, in most of his publications his name was printed as *TÖPLER*.

TOEPLER [or TÖPLER], Maximilian August (1870–1960)

▪ German theoretical physicist; father of electric spark research

The eldest son of August TOEPLER, Maximilian A. TOEPLER was born in Graz, Austro-Hungarian Empire, and followed in his father's footsteps. He studied physics, chemistry, and



mathematics at the Polytechnikum Dresden (1890–1891) and at the Universities of Leipzig (1891–1894) and Göttingen (1894–1895). Already in his habilitation thesis he treated problems of electric discharges, a subject of research with which he was associated until his retirement. In 1900, he was appointed *Privatdozent* (university lecturer) and became associate professor of theoretical physics at the Technische Hochschule (TH) Dresden (1903) and professor and director of the newly founded chair of theoretical physics (1926–1935).

In the period 1907–1908, M.A. TOEPLER repeated the shock visualization experiments of his father (1864), but recorded the propagation and reflection phenomena on film rather than visualizing them subjectively. His technique was similar to the setup used by the U.S. physicist Robert W. WOOD, who had photographed spark waves in the late 1890s. Stimulated by previous observations of his father, who was the first to study the geometry of expanding spark channels – the actual driving force of the *Funkenwelle* (spark wave), a weak shock wave – he focused his interest on the spark channel itself, and investigated the nature of all kinds of spark discharges ranging from point and gliding discharges to ball-lightning. His numerous investigations on spark discharges established his reputation as a leading authority on this subject. He worked out a relationship for the nonlinear, time-dependent impedance of a spark gap, the so-called "Toepler law."

After his retirement (1935), TOEPLER worked temporarily for the German Army as a consultant on schlieren instrumentation for the Heeresversuchsanstalt (HVA) Peenemünde-Ost, which had installed a huge supersonic wind tunnel for aerodynamic rocket model testing. When the TH Dresden, which was heavily damaged in World War II, was reopened, TOEPLER, then already at the age of 78, gave lectures on theoretical physics (1948–1951). In honor of his numerous contributions to research and education, a building of the Faculty of Electrical Engineering on the campus of the TU Dresden, the *Töpler Bau*, was named after him.

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PICTURE. Courtesy Archives of TU Dresden, Photo Collection, Dresden, Germany.

TUPOLEV [Russ. *ТУПОЛЕВ*], Andrei Nikolaevich (1888–1972)

▪ Soviet pioneer in the development of wind tunnels, all-metal airplanes, and supersonic aircraft; father of Russian aviation

Andrei N. TUPOLEV was born in the village of Pustomazovo (near the town of Kimry, in north-western Russia). His father, Nikolai Ivanovich TUPOLEV, was an educated man who worked first as a mathematics teacher, then as a notary, and eventually became a farmer. In 1909, he entered the Moscow Higher Technical School (MWTU) and soon joined Prof. Nikolai E. ZHUKOVSKY's aeronautical course, taking part also in early gliding experiments and in designing Russia's first wind tunnel. After graduation from MWTU (1918) he assisted ZHUKOVSKY in organizing the Central Aerohydrodynamics Institute [ЦАГИ] at Moscow State University [*МГУ*], of which TUPOLEV became director (1918–1935). TUPOLEV was put in charge of the aircraft design department (1920) and appointed head of the Institute's design bureau with the goal of building military and civilian all-metal aircraft (1922). The first Tupolev designs were built at

the German Junkers factory in Moscow, after being taken over by Soviet authorities (1926). His eight-engine ANT-20, the unique "Maxim Gorky" (1934), was the largest aircraft flying anywhere in the world, and his ANT-25, a long-range monoplane, flew across the Arctic to America (1937). After returning from a trip to Germany and the United States (1936), TUPOLEV was unjustly accused of selling secrets to Germany. He was arrested and sent to the Gulag but later placed in charge of a team that was to design military aircraft (1936–1943). In 1944, he was released, received the Stalin Prize for designing the Tu-2 medium-range bomber (1941), and was given a job copying the U.S. B-29 "Superfortress" Heavy Strategic Bomber – three of this type had force-landed in the Soviet Far East – and supervising the building of about 2,000 copies, designated as Tu-4s.

TUPOLEV designed more than 130 types of aircraft. His Tu-104 (870 km/h), a twin-engine turbojet airliner, was introduced in 1955. The turboprop heavy bomber Tu-20 (950 km/h) and the airliner Tu-114 (800 km/h) were the world's fastest propeller-driven aircraft that used the same wings and tail unit. Early in 1963, he set about designing a Supersonic Transport (SST) and appointed his son Alexei Andreevich as chief designer of the Experimental Construction Bureau, and in 1972 his son became general designer after his father's death. The SST Tu-144 ($M = 2.65$) was the world's first supersonic transporter to break the sound barrier during a test flight on December 31, 1968 – only a few months before the British-French "Concorde," the only rival, passed this crucial test. However, plans to also use the Tu-144 as a passenger jet were eventually scrapped in the 1970s due to mismanagement and design problems. One of the four Tu-144 that remained in open storage in the Moscow Zhukovsky Test Base was reactivated in 1995 and used for a series of supersonic test flights operated jointly by Russia and the United States. Besides designing airplanes, he also constructed various types of naval torpedo boats.

TUPOLEV was one of the most decorated Soviet citizens. He was made Hero of Socialist Labor (1945), received many honors and governmental awards such as the Lenin Prize (1957) and three Stalin Prizes for his aircraft design, was elected corresponding member (1933) and Academician (1953) of the U.S.S.R. Academy of Sciences, and acted temporarily as a member of the Commission for Foreign Affairs (1958) and Deputy of the Supreme Soviet. Seventy-three Soviet dignitaries signed his obituary, and tributes to his work were published all over the world.

In 1973, TUPOLEV was honored posthumously when the former Kazan State Technical University (KSTU) – established in 1932 in Kazan, Republic of Tatarstan, Russian Federation, hitherto better known as the "Kazan Aeronautical Institute" – was renamed *A.N. Tupolev Kazan State Technical University*. The *Andrei Tupolev Medal*, awarded by the Aeromodelling Commission of the Fédération Aéronautique Internationale (FAI), was established in 1989 and is donated annually by the National Airsport Control (NAC) of Russia.

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PICTURE. Courtesy Bildarchiv Preussischer Kulturbesitz (bpk), Berlin, Germany.

VIEILLE, Paul Marie Eugène (1854–1934)

▪ French experimental physicist, explosives specialist and inventor

Paul M.E. VIEILLE was born in Paris, where his father, Jules-Marie-Louis VIEILLE, taught mathematics at the Ecole Nor-

male Supérieure. After schooling in Paris and Aix-en-Provence, he decided to study science rather than literature. He began studying mathematics, physics, and chemistry at the secondary school in Marseilles and later at the Ecole Polytechnique (1873–1875). After graduation Vieille entered the Service des Poudres et Salpêtres, a governmental agency in Paris, and was soon entrusted with the office of *Ingénieur du Corps des Poudres*. He was appointed assistant director (1879) of the Laboratoire Central des Poudres et Salpêtres in Paris, then headed by Prof. Emile Sarrau, and later director (1897–1918). He became a member and secretary of the newly founded Commission des Substances Explosives (1878), which was headed by P.E. Marcellin Berthelot and to which Henry L. Le Châtelier also belonged. In addition to his research activities at the Laboratoire Central he took up the respected position of *Répétiteur* at the Ecole Polytechnique (1882–1913).

Vieille improved the bomb calorimeter, which was used in France since 1870 in the study of combustion processes at constant volume, particularly for the measurement of heat generated in an explosion. Together with Berthelot he applied it to thermochemical studies of mercury fulminate and other explosives (1880), performed studies on flame propagation in explosives, and determined the specific heat of gaseous detonation products up to 2,000 °C (1883–1884). Together with Prof. Sarrau he investigated aerodynamic drag of projectiles and invented a crusher gauge to measure the internal pressure of guns (1882). Already in 1884 Vieille had the idea of using a tube of great length, which, eventually leading to the invention of the *shock tube* (1899), is regarded today as his greatest contribution to shock physics. With this technique he studied flame propagation in reactive gases and discovered two basic modes of flame propagation in combustible mixtures: deflagration (slow) and detonation (fast). Vieille's study of colloidal explosives (such as gelatinized nitrocellulose, which possess a nearly homogeneous character) led to the invention of the smokeless powder (1884), known as *"Vieille poudre"* or "*Poudre B*," a straight nitrocellulose of white color [French *poudre blanche*], which was soon after introduced into the French military. It revoluzionized the effectiveness of small guns and rifles, and and later earned him a prize of 50,000 francs set by the French Academy of Sciences (1889). The "Vieille test" (1896) is used in the thermochemistry of propellants to test their thermal stability and compatibility. After 1900, he spent most of his time solving practical problems related to his Poudre B. He also studied the important problem of erosion in gun barrels and found that the gases from the explosion of nitroguanidine were much less erosive than those from other explosives of comparable force (1901).

Vieille became officer of the Légion d'honneur (1890) and member of the Paris Academy of Sciences (1904). In 1952, a new hall at the Laboratoire Central des Poudres in Paris, the *Salle Paul Vieille*, was named after him. Since 1975 the *Paul Vieille Memorial Lecture* has been presented by a distinguished scientist at the biennial International Symposium on Shock Waves in memory of Vieille's numerous contributions to shock waves, ballistics, and detonics. From 1989, the *Prix Pal Vieille* is awarded by the Association Française de Pyrotechnie (AFP) for the promotion of the technical and scientific training in the field of pyrotechnics or related disciplines. The Association des Amis du Patrimoine Poudrier et Pyrotechnique (Association of the Friends of the Heritage in Gun Powders and Pyrotechnics), or Association 3P (A3P), at Paris organizes international meetings called "Journées Scientifiques Paul Vieille," as a tribute to Vieille's famous research in the field of energetic materials during the 19th century.

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PICTURE. Courtesy Collections Ecole Polytechnique, Paris, France.

NOTE. For a list of recipients of *Le Prix Paul Vieille see* http://www.afpyro.org/pvieille. Hitherto five meetings, entitled *Journées Scientifiques Paul Vieille* and organized by the Association 3P, were held in France with the following topics: (1) *100th anniversary of the invention of solvent-less gun propellants* [Vert-le-Petit, Sept. 1984]; (2) *Influence of explosives materials in reducing the vulnerability of ammunitions* [Brest, Oct. 1991]; (3) *Instrumentation, experimentation and expertise of energetic materials since the XVIth century* [Paris, Oct. 2000]; (4) *History of solid propellants during the XXth century* [Paris, Oct. 2003]; and (5) *1945-2005: sixty years of modern pyrotechnics* [Paris, Nov. 2006]; *see* http://association.a3p.free.fr/anglais/colloques_a.htm.

WALLIS, John [Lat. *Johannus*] (1616–1703)

▪ English mathematician and cryptographer; early pioneer of percussion mechanics

John WALLIS was born in Ashford, a town in Kent. His father was the Rev. John WALLIS. He began his education in Latin at a private school in Tenterden, Kent (1625), and continued in Greek, Hebrew, and logic at Felsted School, Essex (1630). At Emmanuel College in Cambridge he studied natural philosophy, ethics, metaphysics, theology, anatomy, and medicine and graduated with a B.A. (1637) and an M.A. (1640). After ordination (1640) he became domestic chaplain, first to Sir Richard DARLEY and later to Baroness Mary VERE in London. Because of his particular ability to decipher letters in code, he was employed by the parliament as a cryptographer to decipher intercepted dispatches (1642–1645), an activity which he later resumed for king WILLIAM III (1690). After inheriting a considerable estate (1643), he dedicated himself entirely to science and became a Fellow of Queen's College in Cambridge (1644). WALLIS was appointed to the Savilian Chair of geometry (1649–1703) at Oxford University by Sir Oliver CROMWELL and later became keeper of the University Archives (1658–1703). He was made a doctor of divinity (1654) and became a royal chaplain (1660) and F.R.S. (1663). In addition, he acted temporarily as secretary to the assembly of divines at Westminster in London. During his period in London (beginning in 1645) he made the acquaintance of numerous scientists who met regularly at the lodgings of the physician Dr. Jonathan GODDARD in Woodstreet, London. These meetings formed the nucleus of the later Royal Society of London (founded in 1660). WALLIS was one of the founding members.

During his Savilian professorship he published his famous book *Arithmetica infinitorum* ("The Arithmetic of Infinitesimals," 1655), which contains the germs of the differential calculus, and extended higher algebra. With his method of interpolation he introduced the principles of analogy and continuity into mathematical sciences and invented the symbol ∞ for infinity using 1/∞ to represent an infinitesimal height. Under the heading *Johannis Wallisii ... operum mathematicorum* (*Pars altera* 1656, *Pars prima* 1657) he also published several mathematical treatises that were partly an outcome of his university lectures. His last great mathematical work was *A Treatise of Algebra, both Historical and Practical* (1685).

WALLIS, like Christiaan HUYGENS and Christopher WREN, also contributed considerably to the problem of percussion and impact, which in the 1660s was a much discussed sub-

ject at the Royal Society and the French Academy. In a paper submitted in 1668 to the Royal Society and published in the following year in the journal *Philosophical Transactions*, he treated inelastic percussion, equating elasticity with less-than-perfect hardness. These studies were extended to elastic percussion in the third part of his voluminous book *Mechanica, sive de moti tractatus geometricus* ("Mechanics, or Geometrical Tracts on Motion"), published in the period 1670–1671, then the most thorough study of mechanics and motion prior to Sir Isaac NEWTON's *Principia* (1687). Refuting many of the errors regarding motion that had persisted since the time of ARCHIMEDES, he gave a more rigorous meaning to such terms as force and momentum and widened the scope of treating mechanical problems analytically. The first part of his *Mechanica*... deals with various forms of motion in a strictly "geometrical" (*i.e.*, Euclidean) form, introducing the idea of moment, in modern terms the moment of inertia, which is essential for inquiries into the center of gravity and the center of percussion. The second – major – part deals with the calculation of the center of gravity. In the third part he discusses, in addition to problems on percussion, elementary machines that, according to ancient tradition, encompassed the lever, wedge, wheel and axle, pulley, and screw.

Later, in the first volume of his three-volume *Opera mathematica* (Oxford 1695) in which he edited his own mathematical works, he resumed the subject of percussion: he discovered in bodies that are freely rotating around a fixed axis and eccentrically struck by an impulsive force particular properties of a so-called "center of percussion" [Lat. *centrum percussionis*]. WALLIS first noticed that in a compound pendulum the center of percussion is identical to the "center of oscillation" as described by HUYGENS in his *Horologium oscillatorium* (Paris 1673).

WALLIS also published sermons and collections of his own theological tracts (1691) and an English grammar (1652). He edited classical mathematical authors (1676–1688) and published more than 60 papers and book reviews in the *Philosophical Transactions* (1666–1702).

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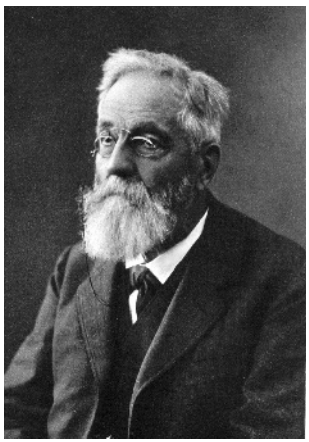
PICTURE. From his book *Opera mathematica* (1695), frontispiece of vol. 1.

WEBER, Heinrich Martin (1842–1913)

▪ German theoretical and applied mathematician



Heinrich M. WEBER was born in Heidelberg to the noted historian Georg WEBER and studied mathematics and physics at the Universities of Heidelberg (1860–1861) and Leipzig (1860–1862). At Heidelberg University he earned his Ph.D. (1863). In 1866, he prepared for his habilitation as *Privatdozent* (university lecturer) and 3 years later became extraordinary professor. After teaching mathematics at the ETH Zürich (1869–1875) and the University of Königsberg (1875–1883), he was appointed professor of mathematics at the Technische Hochschule Berlin-Charlottenburg (1883) and subsequently

taught in this discipline at the Universities of Marburg (1884–1892), Göttingen (1892–1895), and Strassburg (1895–1913). The direction of his work was decisively influenced by his stay at Königsberg, where in the period 1827–1842 the mathematician and greatest algorist of all time Carl G.J. JACOBI had worked on elliptic functions and made important contributions to the theory of determinants, so-called "Jacobian mathematics." At Königsberg WEBER was encouraged by Franz E. NEUMANN to investigate physical problems and by Friedrich Julius RICHELOT to study algebraic functions.

In 1868, WEBER published a paper entitled *Über eine Transformation der hydrodynamischen Gleichungen* ("On a Transformation of the Hydrodynamic Equations") in which he shows that in the case of using *Lagrangian* coordinates (in opposition to *Eulerian* coordinates) the system of differential equations of the second order can be transformed by a partial integration into a system of first-order differential equations, which becomes particularly simple in the case of using a velocity potential.

Together with J.W. Richard DEDEKIND, a mathematician and his closest friend, he edited G.F. Bernhard RIEMANN's collected works (1876). Based upon the lecture notes of Karl HATTENDORFF – one of RIEMANN's former students at Göttingen who had published in 1869 the book *Partielle Differentialgleichungen und deren Anwendung auf physikalische Fragen: Vorlesungen von Bernhard RIEMANN* ("Partial Differential Equations and Their Application on Physical Problems. Lectures of Bernhard RIEMANN") – WEBER reworked HATTENDORFF's book and in 1900/1901 edited Bernhard RIEMANN's posthumously published lectures on the theory and application of partial differential equations in the two-volume book *Die partiellen Differentialgleichungen der mathematischen Physik* ("Partial Differential Equations of Mathematical Physics"). In this book, which went through three editions, WEBER also addressed the fundamentals of thermodynamics and shock waves in gases with numerous examples.

In 1871, WEBER edited Charles BRIOT's *Lehrbuch der mechanischen Wärmetheorie* ("Textbook on the Mechanical Theory of Heat") and in 1907, together with Josef WELLSTEIN, the three-volume *Enzyklopädie der Elementar-Mathematik* ("Encyclopedia of Elementary Mathematics"). He also published the three-volume *Lehrbuch der Algebra* (1895–1896), an important textbook on algebra that was widely used in teaching and research for decades.

WEBER was a cofounder of the Deutsche Mathematiker-Vereinigung (1890) and a member of the editorial board of the journal *Mathematische Annalen* (1893–1913). His most prominent students were Hermann MINKOWSKI, David HILBERT, Adolf KNESER, and Robert FRICKE.

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PICTURE. From the frontispiece of the *Festschrift H. WEBER* (1912).

WIESELSBERGER, Carl (1887–1941)

▪ German aerodynamicist

Carl WIESELSBERGER was born in Eberstahl, Lower Bavaria, and took his Ph.D. in general mechanical engineering at the TH Munich (1913). From 1913 to 1922 he was assistant and department leader at the Aerodynamische Versuchsanstalt (AVA), an aerodynamic testing facility in Göttingen. He made important contributions to the design of the Göttingen wind tunnel (1917) and carried out numerous investigations on aerodynamic drag and its dependency on surface friction and roughness. Invited by the Japanese government, he stayed at the Imperial University in Tokyo, where he significantly contributed to the design of Japanese wind tunnels

(1922–1930). After his return to Germany he was appointed chair of aeronautics at the TH Aachen and became director of the Aerodynamics Institute (1930–1941).

During this period WIESELSBERGER got involved in problems of high-speed aviation, both theoretically and experimentally. At the 5th Volta Conference in Rome (1935) he gave the first correct explanation of the puzzling phenomenon of the "X-shock," hitherto observed in high-speed wind tunnels. Since it is caused by the humidity of the air, it is therefore also called "condensation shock." He also suggested a specific wind tunnel configuration with 46% of the perimeter open via two wide longitudinal slots to reduce the blockage effect (1942). When, after the war, Ray H. WRIGHT and John STACK took up again the wind tunnel technique that used longitudinal slots (1947), WIESELSBERGER's concept resulted in NACA's many-slotted wind tunnel (1947). WIESELSBERGER developed various measurement techniques and instruments related to fluid dynamics and practical aviation, such as the wind tunnel balance (1934). Under his direction, Rudolf HERMANN, one his assistants, designed, built, and operated the Aachen supersonic wind tunnel, a little blow-down-type facility with a 10×10 cm^2 test section, operable up to $M = 3.3$ and equipped with a three-component balance (1931–1933). This very efficient concept of the Aachen supersonic wind tunnel was later closely followed up in the design of the larger Peenemünde wind tunnels (1937–1945).

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PICTURE. From the commemorative publication *50 Jahre Aerodynamisches Institut der RWTH Aachen 1913–1963*, courtesy Universitätsarchiv der RWTH Aachen, Germany.

WOOD, Robert Williams (1868–1955)

▪ U.S. experimental physicist, father of infrared and ultraviolet photography

Robert W. WOOD was born in Concord, MA, the son of Robert Williams WOOD, a physician and pioneer in the sugar industry. After graduating in chemistry from Harvard University (1891), he entered Johns Hopkins University (1892) and became an Honorary Fellow of the University of Chicago (1892–1894). In order to complete his studies in chemistry, WOOD decided to continue his studies at the University of Berlin (1894–1896), but, coming there under the influ-

ence of Heinrich RUBENS, a professor of experimental physics, he became more interested in physics. Two years later, after his return to the United States, he spent a short time at MIT, where he was appointed instructor (1897). Thereafter, he became assistant professor (1899) of physics at the University of Wisconsin (1899).

WOOD's main interest was physical optics, but in order to demonstrate to his students the wave properties of light, he used wave fronts of sound waves, which he generated by electric spark discharges. Like August TOEPLER, he studied the propagation and reflection of spark waves (*i.e.*, weak shock waves) and, with the support of Sir Charles V. BOYS, was the first to photograph and present this subject to a British public. In the period 1901–1938 he again joined Johns Hopkins University, where he served as professor of experimental physics until his retirement, achieving there great popularity as a teacher of physics and as an outstanding demonstration lecturer. WOOD contributed significantly to spectroscopy by developing the technique of Raman spectroscopy, helped to develop color photography, conducted significant research on the physical properties and biological effects of ultrasonic waves, and devised practical uses for infrared and ultraviolet light. He invented a filter for ultraviolet transmission, which excluded all visible light, and was the first to publish infrared photographs (landscapes) taken on experimental film (1910).

After his retirement WOOD worked as research professor (1938–1953), serving also as a consultant to the Manhattan Project and to Aberdeen Proving Ground. He was the first to propose the use of tear gas and the use of air space around warships to dissipate the destructive power of torpedoes when the ship is attacked. Towards the end of World War II, the irregular reflection of shock waves (Mach reflection) became of great interest to optimize the Height of Burst (HOB) of the first atomic bomb to be dropped on Japan in regard of maximizing the overpressure (and supposedly also the destruction) on the ground. Renowned for his early sound wave reflection studies (1899), WOOD entered the field of shock waves again in 1943, when – then at the age of 75 – he was enlisted by John von NEUMANN at Princeton's Institute of Advanced Study (IAS) to repeat Ernst MACH and Jaromir WOSYKA's soot experiments on the oblique interaction of shock waves, which they had performed in 1875 at the German Charles University in Prague. WOOD's results, fully confirming the existence of Mach reflection, were an important basis for subsequent refined shock-tube measurements carried out by Walter BLEAKNEY's group at Princeton.

WOOD wrote over 200 scientific articles and two books. His textbook *Physical Optics* (1905) became a classic in the art of experimental optics, of which he finished a revised 4th edition shortly before he died in 1955. After 1920, WOOD made important contributions to the fields of ultrasound and biophysics by studying the biological and physiological effects of high-frequency sound waves. He wrote the book *Supersonics, the Science of Inaudible Sounds* (1939); at that time the term "supersonics" (dealing with phenomena arising when the velocity of a solid body exceeds the speed of sound) was formerly applied to "ultrasonics" (dealing with high-frequency sound waves).

WOOD's numerous contribution to physics, particularly to physical optics, were honored by medals from the Optical Society of America (OSA), the American Academy of Arts and Sciences (AAAS), the National Academy of Sciences (NAS), the Royal Society of London, the London Society of Arts, and the Franklin Institute. He was a Fellow of the American Physical Society and an honorary member of OSA. The *R.W. Wood Prize*, established by OSA in 1975 to honor the many contributions that WOOD made to optics, recognizes an outstanding discovery, scientific or technical achievement, or invention in the field of optics.

A crater on the far side of the Moon is named for him.

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PICTURE. Courtesy The Ferdinand Hamburger Archives of The Johns Hopkins University, Baltimore, MD.
NOTE. WOOD's manuscripts are kept at the Milton S. Eisenhower Library, Johns Hopkins University.

WREN, Sir Christopher (1632–1723)

▪ English architect, designer, geometrician, and astronomer; early pioneer of percussion mechanics

Sir Christopher WREN was born in East Knoyle in the County of Wiltshire as the son of Christopher WREN, then serving as rector of East Knoyle and chaplain to King Charles I, king of Great Britain and Ireland. He began his studies of the natural sciences at Westminster School in London and graduated (M.A.) from Wadham College in Oxford (1653). He became Fellow of All Souls College (1653–1661) in Oxford and professor of astronomy at Gresham College in London (1657–1661) and at Oxford University (1661–1673). His early life was marked by an interest in mathematics and natural science, particular in mechanics, but at the age of 30 he turned to architecture and made his first architectural designs. He probably applied himself to architecture and visited France (1665), where he studied the buildings erected in the period of LOUIS XIV, king of France (1643–1715). After his return to England, he prepared a scheme for rebuilding London after the Great Fire (1666) and was appointed Surveyor-General and Principal Architect for rebuilding the entire city (1668).

In the same year, Sir WREN submitted a paper on percussion to the Royal Society, which he had already written several years earlier – thus fulfilling an urgent request by Henry OLDENBURG, secretary of the Society who had asked several leading authorities in Europe to treat this subject of general interest. Together with DESCARTES, GALILEI, HUYGENS, MARCI, MARIOTTE, Sir NEWTON, and WALLIS, he belongs to the early-17th-century pioneers who investigated percussion phenomena scientifically, their results forming a significant base for subsequent researchers on this subject.

Sir WREN's short paper on the Laws of Motion in the case of two bodies impacting head-on was published in the journal *Philosophical Transactions*, immediately following John WALLIS' paper treating the same subject. Sir WREN limited his study to the case of a perfectly elastic collision, so that no motion is lost and the sum of the two products of mass and velocity is constant; *i.e.*, using correctly the Law of Conservation of Momentum. Attempting to solve a dynamic problem by a static approach, he plotted the velocities before and after percussion along a velocity axis forming a balance swinging about its center of gravity. Unfortunately, his geometrical solution – somewhat obscure but providing correct results and proved by him experimentally – was given by him without proof. Generally, the solution to this two-body percussion problem requires the application of both the Law of Conservation of Momentum and the Law of Conservation of Energy. At that time, however, the latter fundamental principle of mechanics was not yet recognized, and this fact even underlines the ingenuity of his solution. Very recently, Kerry DOWNES, a history of art professor at Reading University and WREN biographer (*see below*), appropriately wrote: "Contemporaries complained that he [WREN] valued the neatness of a solution above the presentation of proofs, claiming that the truth, once stated, was self-evident… As in the case of PASCAL, he preferred geometrical, visual, and intuitive solutions for mathematical problems."

Sir WREN was a founding member of the Royal Society of London (founded in 1660) and served as its third president (1680–1682). He was knighted in 1673. His scientific work was highly regarded by Sir Isaac NEWTON, who specifically recognized his experiments with suspended balls as confirming one of his three Laws of Motion. Today Sir WREN is more renowned for his contributions to British architecture rather than to science. He designed and rebuilt 52 city

churches in London; his best-known work is certainly St. Paul's Cathedral (1675–1710), the world's third largest church and his burial place. Other famous buildings he designed are the Sheldon Theatre in Oxford and the Pembroke College and the Library of Trinity College in Cambridge. Together with his colleague and friend Robert HOOKE, WREN also designed the monument on Fish Street, which commemorates the Great Fire.

A crater on Mercury is named for him.

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PICTURE. Courtesy Deutsches Museum, Munich, Germany.

YEAGER, Charles ("Chuck") Elwood (1923–)

▪ U.S. aviator and test pilot, the "Supersonic Man"

Charles E. YEAGER was born in Myra, WV, the son of Albert YEAGER, a driller for natural gas in the West Virginia coal fields. Enlisting in the U.S. Army (1941), he was commissioned a reserve flight officer (1943) and became a pilot in the fighter command of the 8th Air Force stationed in England. He flew 64 missions over Europe during World War II and was shot down by German aircraft. After the war he became a flight instructor and then a test pilot. He was chosen from several volunteers to test-fly the X-1, a secret experimental aircraft built by the Bell Aircraft Company to test the capabilities of human pilots and fixed-wing aircraft against the severe aerodynamic stresses of sonic flight. On October 14, 1947 – only days after cracking several ribs in a horseback riding accident but not wishing to disrupt the testing schedule – YEAGER broke the sound barrier over Rogers Dry Lake in southern California. His X-1, attached to a B-29 mother ship and carried to an altitude of 7,600 m, then rocketed separately to 12,000 m, reaching in level flight a supersonic velocity of 1,066 km/h (296 m/s). The feat was not announced publicly until June 1948. He continued to make test flights, and on December 12, 1953, flying the rocket plane Bell X-1A, he became the first person to exceed Mach 2, thereby establishing a world speed record of 2,660 km/h. Today, the orange rocket plane is part of the collection of the Smithsonian Institution of Technology in Washington, DC.

YEAGER, renowned as the "Supersonic Man," held various air force command assignments between 1954–1962, was vice-commander of the Ramstein Air Force Base in Germany (1968–1969), and retired from active duty in the Air Force with the rank of brigadier general (1975). For his numerous contributions to the advance of aeroscience he was honored with the Fédération Aéronautique International Gold Medal (1947), the Collier Trophy (1948), the Harmon International Trophy (1953), and the Presidential Medal of Freedom (1985). In 1966, he was inducted into the International Aerospace Hall of Fame. YEAGER's autobiography was published in 1985. He appears as the main character in Tom WOLFE's book *The Right Stuff* (1979), and as the epitome of that virtue he appeared in numerous commercial endorsements.

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PICTURE. Courtesy Deutsches Museum, Munich, Germany.

ZEL'DOVICH [Russ. *ЗЕЛЬДОВИЧ*], Yakov Borisovich (1914–1987)

▪ Soviet chemical physicist, nuclear physicist, astrophysicist, and shock wave and detonation physicist; cofounder of modern detonation theory

Born in Minsk, Belorussia (Belarus) the son of an attorney, Yakov B. ZEL'DOVICH began his scientific career as a laboratory assistant in the department of chemical physics at the Leningrad Institute of Chemical Physics of the U.S.S.R. Academy of Sciences (1931). The Institute, then directed by Prof. Nikolai N. SEMENOV, was also involved in the crystallization of nitroglycerin in two modifications. Very soon his talent for theory was discovered, and he was transferred to the theoretical department. Here mathematicians and physicists provided him with continuous instruction on the foundations of theoretical physics, and with their help he received a thorough education. He never graduated from a university, although he was the author of over 20 books and 500 scientific articles on subjects ranging from chemical catalysis to large-scale cosmic structures, with major contributions to the theory of combustion, detonation, elementary particles, and astrophysics. However, his exceptional talent enabled him to embark on a postgraduate career, which he successfully completed with a Ph.D. thesis entitled *Oxidation of Nitrogen in Combustion and Explosions* (1939), which, containing a multitude of experimental and theoretical data, proved that the oxidation of nitrogen is an unbranched chain reaction.

ZEL'DOVICH and his colleague David A. FRANK-KAMENETSKII, an outstanding theorist, worked out a theory of flame propagation and proposed a mechanism for chemical reactions in a shock wave (1938–1943). An understanding of the features of the combustion of powders served as a basis for creating the internal ballistics of solid-fuel rockets: research carried out during World War II was orientated toward the *Katyusha* ("Little Katie," the title of a famous Russian song). This rocket weapon consists of a launcher capable of being fired in a salvo, popularly known as the "Stalin organ." Motivated by his patriotism, he also contributed to the development of the first Soviet atomic bomb and together with Yulii B. KHARITON did important theoretical research on nuclear chain reactions (1939–1941).

In the shock physics community his reputation rests primarily on his theoretical contributions to shock waves and detonation. In 1940, he completed his 1-D theory of detonation, 2 years prior to John VON NEUMANN. His work on the theory of shock waves fell into the period 1946–1969 and encompassed (1) the systematic use of physical concepts in gas dynamics; (2) experimental studies of physicochemical kinetics in gases at high temperatures using shock tubes; (3) investigations on the structure of shock waves, particularly the possibility of rarefaction waves with discontinuities; (4) a quantitative theory of observed front patterns of shock-induced luminescence; and (5) experimental methods to study the dependence of the refraction and polarization coefficients of optically transparent substances during strong shocks.

He also made significant contributions to the theory of combustion and detonation by bringing together gas dynamics, gas-kinetic theory, molecular transport effects, and the kinetics of high-temperature chemical reactions. In 1940, he developed a steady-state detonation model that was independently proposed in the United States by John VON NEUMANN (1942) and in Germany by Werner DÖRING (1941) and that is known today as the "Zel'dovich-von Neumann-Döring (ZND) theory." In the same year, ZEL'DOVICH also considered the application of detonations to propulsion and power engineering.

Together with Yuri P. RAIZER he published in 1963 the Russian textbook *Fizika udarnych voln i vysokotemperaturnych dinamiceskich javlenij* ("Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena"). It was

translated into English (1966–1967) and recently reprinted (2002). ZEL'DOVICH's contribution to the theory of shock waves has been reviewed by Y.P. RAIZER, one of his former coworkers (*see also* his introduction in the *Selected Works of Yakov B. ZEL'DOVICH*). Beginning in the 1960s, ZEL'DOVICH's interest in basic research shifted increasingly to cosmology and cosmogony, particularly to the origin of the Universe.

In the 1960s, ZEL'DOVICH worked on astrophysics and cosmology. First suggesting a "cold model variant" to the origin of the Universe (1962), he immediately became an enthusiastic advocate of the "Hot Big Bang model" when the phenomenon of a residual microwave background radiation at about 3 K was discovered by Arno A. PENZIAS and Robert W. WILSON (1965). Together with the Russian theoretical astrophysicist Rashid A. SUNYAEV he predicted in 1969 the so-called "Sunyaev-Zel'dovich effect." Measurements of this effect provide distinctly different information about cluster properties than X-ray imaging data, while combining X-ray and Sunyaev-Zel'dovich effect data leads to new insights into the structures of cluster atmospheres and the structure of the Universe on the largest scales.

He also worked on the dynamics of neutron emission during the formation of black holes, the formation of galaxies and clusters, and the large structure of the Universe. Together with his followers he made his Moscow Sternberg Astronomical Institute a stronghold of relativistic astrophysics.

He received many national and international awards and medals. He was elected corresponding member (1946) and Academician (1958) of the U.S.S.R. Academy of Sciences and foreign member of various other highly regarded academies. Cambridge University awarded him an honorary doctorate. In his later years he tried to emigrate, but this was twice prevented. Recently, Prof. Lev V. AL'TSHULER, the patriarch of Russian shock wave research who closely collaborated with ZEL'DOVICH for a long time, retrospectively summarized his scientific biography: "YA. B. ZEL'DOVICH lived through a whole number of careers, each devoted to explosions of one kind or another, whose power progressively increased as his interest shifted from the detonations and explosions of chemical substances, through increasingly powerful chain reactions and nuclear explosions, and finally to the Big Bang, from which the Universe emerged 15 billion years ago. Combustion and detonation were ZEL'DOVICH's first and lifelong love, a passion to which he remained faithful until his last days."

The 1994 and 2004 International Conferences on Combustion Detonation and Shock Waves, organized by the Scientific Council of the Russian Academy of Sciences and held in Moscow, were dedicated to his 80th and 90th birthday anniversaries and renamed the *Zel'dovich Memorial I* and *Zel'dovich Memorial II*, respectively. The *Ya.B. Zel'dovich Gold Medal*, established in 1990 by The Combustion Institute, is awarded "for outstanding contribution to the theory of combustion or detonation."

A minor planet (asteroid 11,438 ZEL'DOVICH) was named after him.

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PICTURE. Courtesy Deutsches Museum, Munich, Germany. The photo shows Y.B. Zel'dovich (*right*) together with Y.B. Khariton.
NOTE: His name has also been transliterated as Zel'dovič.

Zemplén, Györ Victor (1879–1916)

▪ Hungarian physicist

Gyözö V. Zemplén was born in Nagy-Kanizsám, then a town in the Hungarian part of the Austro-Hungarian Empire, and attended the gymnasium in Fiume (now Rijeka, Croatia). Already very early interested in natural sciences, he won at the age of 19 the Johann Pasquich Prize with a work on the inner friction of gases. After studying mathematics and physics at the Múegyetem (Royal Josephs Polytechnic), he took his *Magister* degree and became assistant at the institute of experimental physics of Prof. Roland von Eötvös, the most significant Hungarian physicist of that time.

Zemplén critically reviewed contemporary hypotheses on the kinetic theory of gases (1900) and proposed a new method of measuring the viscosity of gases and liquids using a torsion pendulum, which earned him the Ph.D. (*sub auspiciis regis*) and the Than Károly Prize (1901). Thereafter, he won a research fellowship (1904–1906) and visited the Universities of Göttingen and Paris. At Göttingen he became interested in the mathematical treatment of hydrodynamic nonlinear differential equations and the physical interpretation of their solutions (1905).

Zemplén also propounded the idea that shock waves can only be compression waves, meaning that rarefaction shocks (*i.e.*, negative shocks) cannot exist, the so-called "Zemplén theorem." He presented his results in Göttingen at Felix Klein's seminar, then an international authority on mathematics, and in Paris at the French Academy, which resulted in fruitful discussions with Jacques Hadamard and Pierre Duhem, two experts in the young discipline of shock waves. In the following year, he published his study in the prestig-

ious French journal *Comptes rendus de l'Académie des sciences* and the German *Enzyklopädie der Mathematischen Wissenschaften*.

ZEMPLÉN's personal contacts to leading French shock scientists of his time, his great expertise, and his publications in Hungarian, French, and German certainly contributed to a quick spreading of the new term *shock wave*, which, used first by E. MACH and J. WENTZEL [Germ. *Stoßwelle*, 1885] and later by HADAMARD [French *onde de choc,* 1904], was picked up immediately by ZEMPLÉN (1905).

Returning to Budapest, ZEMPLÉN habilitated (1907), worked as a *Studienrat* (Assistant Master) at the University of Budapest, and eventually became full professor and director of the newly founded Chair and Institute of Theoretical Physics. Besides his contributions to gas dynamics and hydrodynamics, ZEMPLÉN began working in mechanics, electrodynamics, and X-rays. However, at the beginning of World War I he was called up and killed in the battle at Monte Dolore (1916), northern Italy, at the early age of 37.

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PICTURE. Courtesy Library & Information Center, TU Budapest, Hungary.

ZHUKOVSKY [Russ. *ЖУКОВСКИЙ*], Nikolai Egorovich (1847–1921)

▪ Russian physicist and mathematician; father of Russian aviation and founder of Russian hydro- and aeromechanics

Nikolai E. ZHUKOVSKY was born in Orekhovo, Vladimir Oblast (western Russia). His father was a railway engineer. After attending the 4th Gymnasium for Men in Moscow (1864), he graduated in physics and mathematics at the Moscow State University [*МГУ*] (1868) and was appointed professor of mechanics at the Moscow Technical School (1872). After earning his Ph.D. (1882) from Moscow State University for a thesis on the stability of motion, he became professor of theoretical mechanics and head of the department of mechanics (1886). He built the first Russian wind tunnel to study various profile forms (1891). At the Moscow Higher Technical School he gave the world's first systematic lectures on the theoretical foundations of aeronautics (1911–1912). During World War I he taught a special course for pilots at Moscow State University and organized an association of aeronautics that was later transformed into the famous Central Aerohydrodynamics Institute [CAGI, Russ. *ЦАГИ*], which soon became the leading Russian school of hydrodynamics and aerodynamics (1918). In the 1920s, he also organized the Aviation Engineering Academy. At the turn of the century ZHUKOVSKY and collaborators investigated the generation and propagation of shock waves in water supply lines. They studied the dreaded hydraulic impact, which they called the "water hammer effect," and possible measures of its prevention.

ZHUKOVSKY was a very versatile researcher: he invented a device for testing airscrews, wrote on the theory of ships, investigated propeller thrust and the most efficient angle of attack of a wing, the resistance of moving bodies in a stationary liquid, and the generation of turbulence, established the kinematic laws of particles in a current, and was the first to apply conformal transformation to convert a circle into an airfoil profile, the so-called "Zhukovsky profile" (1910). Independently of the German mathematician Wilhelm KUTTA, ZHUKOVSKY discovered the condition of smooth flow at the

trailing edge of a 2-D wing, the so-called "Kutta-Zhukovsky equation" (1912).

Known already during his lifetime as one of the foremost authorities in the world of aeronautics, ballistics, and hydromechanics, a governmental decree honored him with the title "Father of Russian Aviation" (1920). He published about 200 papers on mechanics, which mostly treated problems of aerodynamics and hydrodynamics, and laid the basis of Soviet aviation and industry. His collected works were published in seven volumes from 1948 to 1950.

He was a corresponding member of the Russian Academy of Sciences, and a member of the Moscow Mathematical Society, serving also as its president (1905–1921). In 1922, the Russian Academy of Science established the *Zhukovsky Prize* for research in the area of aerodynamics of aircraft. Today ZHUKOVSKY is considered the founder of Russian hydromechanics and aeromechanics. In commemoration of his services the School of Aviation, which evolved from *ЦАГИ*, was named *N.E. Zhukovsky Academy of Military and Aeronautical Engineering* (1922). On the occasion of the 100th anniversary of his birth, the city of Stakhanovo, located on the Moskva River about 20 km southeast from Moscow and the home of *ЦАГИ*, was renamed in 1947 "Zhukovsky (City)" [*Жуко́вский*].

A crater on the far side of the Moon is also named for him.

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PICTURE. From *The MacTutor History of Mathematics Archive*, School of Mathematics and Statistics at the University of St Andrews, Scotland; http://www-groups.dcs.st-and.ac.uk/~history//PictDisplay/Zhukovsky.html.

NOTE. His name has also been transliterated as JOUKOVSKY, JOUKOWSKI, SCHUKOWSKII, SHUKOWSKI, ZHUKOVSKII, and ŽUKOVSKIJ.